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KINÆSTHETIC AND ORGANIC SENSATIONS: THEIR ROLE IN THE REACTIONS OF THE WHITE RAT TO THE MAZE

BY

JOHN B. WATSON

INSTRUCTOR IN PSYCHOLOGY, AT THE UNIVERSITY OF CHICAGO
STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF THE
UNIVERSITY OF CHICAGO

PREFACE.

In this place, I wish to state my deep indebtedness to Professor James Rowland Angell for his many kindly criticisms and suggestions both as regards the content and the form of the present paper.

Dr. Harvey Carr has given me great assistance in the conduct of the experimentation. I have tried where possible to indicate the work for which he alone is responsible. During the past summer, 1906, he devoted a large part of his time to coöperating with me upon experiments described in the paper under headings, Part B, IV. and VI.

I am also indebted to Professor George H. Mead and to Professor Henry H. Donaldson for their many valuable suggestions.

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JOHN B. WATSON.

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I. INTRODUCTION.

(a) THE NATURE AND THE GENERAL BEARINGS OF THE PRESENT STUDY.

In a short address given before the Section on Genetic and Comparative Psychology of the Congress of Arts and Sciences, St. Louis, 1904, the writer sketched a possible experimental method in Comparative Psychology, which would have for its goal the determination of the relative importance of the several sensations of any given animal in its adjustment to its environment. As a matter of fact, the method, as outlined there, consists in adapting an established method to meet new conditions.

For many years, physiologists have made use of vivisectional experiments to determine the function of specific organs. Their results have been of immense value both to the physiologist and to the psychologist. On the whole, however, these experiments have usually been made upon untrained animals for the purpose of testing the relatively immediate and local effects of the given operation.[1] Naturally, in such experiments, the physiologist has given little attention to the effect of the operations upon the instinctively and, habitually organized reactions of the animal as a whole. Here is, undoubtedly, a new field for the student of animal psychology; a field which must be worked over from the psychophysical standpoint, in contradistinction to the purely physiological one. As is well known, this method has already been applied to the study of defective human beings who have lost or who have never possessed one or several sense-organs, and as a result of the appli-

[1] Shepherd I. Franz's experiments to determine the relation of the frontal lobes to the production and retention of simple sensory-motor habits in cats, *Am. Jour. Physiology*, 1902, Vol. VIII., p. 1 ff., form an exception. His method is practically identical with the one adopted here. Cf. also this author's 'Observations on the Functions of the Association Areas (cerebrum) in Monkeys,' *Jr. Amer. Med. Association*, November 3, 1906, Vol. XLVII., pp. 1464-1467.

cation of this method, a flood of light has been thrown upon the complicated human mental processes as a whole. It is natural to suppose that the study of blind, deaf and anosmic animals may, in a similar way, throw as much light upon the totality of the mental processes of animals. In the case of human subjects, born with defective organs, our interests are mainly concerned with the way in which an organized mind can develop and react upon its environment, when the material upon which it depends for its growth is limited in kind. In the case of human subjects who have suffered either sense organ defects, or defects of the corresponding cortical centers in conjunction with these, after the mental life has become organized, we are interested principally in the reshaping and in the reconstruction of the mental life, as evidenced by the changed behavior of the individual experiencing the defect. Our interests, then, in defective minds are functional; we are interested in the content of such minds only in so far as the analysis of their content will lead to the understanding of the behavior of the subject. So much has been said to show that, from the standpoint of method, the study of minds of animals (normal or defective) does not essentially differ from the study of human defective minds and the minds of children. In view of the fact that in the investigation of the mental life of animals, we are forever barred from studying content (by way of introspection), a certain limited number of psychologists and physiologists are inclined to underestimate the value of the comparative method. The present paper will not attempt to justify comparative psychology; it will take its justification for granted, relying upon the fact that the criticisms directed against the study of the mental processes of animals are valid only from the standpoint of a structural and statical psychology. They have no significance from a functional point of view.

Detailed and careful studies of the sense organ processes of animals will aid us in the end, we feel sure, not only in understanding the organized reactions of the particular species of animal studied, but also in bringing about the possibility of a closer functional comparison of human sense organ processes

with those of animals. The value and general bearings of such studies are well recognized, but the pressing need of such knowledge as a basis for further studies in animal psychology is not so thoroughly emphasized. Elsewhere[1] we have tried to show, that certain problems in animal behavior are, in the writer's opinion at least, not rightly answered today because of the lack of detailed knowledge of the principal avenues over which animals receive their most important sensations. The questions (stating them in conscious terms) are not so much, " Can my animal see? Can he hear? Can he smell? " etc. The problem is, rather, " How well can he see *objects?* Well enough for vision to serve as a specific basis for reacting to them? " " Or does light serve merely as a stimulus (possibly mainly affective) to arouse general activity, while the details of the ensuing adjustment are left by vision to be carried out by other groups of sensations? " It is easy to see that the answer to these questions must make a world of difference in our presentation of problems to him.

In the present paper, we shall deal with some experiments upon the sense organs of the white rat, the results of which we hope will put us in a position to begin a more scientifically based study of his mental processes. These experiments have occupied a large part of the writer's time for a period of eighteen months. The maze (kind, method, etc., to be described separately further on), was chosen as being the problem best adapted to the structure and habits of the white rat. The eminent fitness of the maze to serve as a " rat problem " has already been described by Small.[2] We shall now turn to a study of his experiments upon the rat and to those of other investigators who have observed different animals at work upon this problem.

(b) A SUMMARY OF THE WORK DONE BY OTHER INVESTIGATORS UPON THE NORMAL PROCESS OF LEARNING THE MAZE.

As may be surmised from the title of this paper, the present study grew directly out of the repetition of Small's experiments

[1] *Psychological Bulletin,* Vol. III., No. 5.
[2] *Am. Jr. Psy.,* Vol. 12, pp. 206–239.

with rats in the (modified) Hampton Court maze, and it may be said frankly in the beginning, that the outcome of the investigation does not go far beyond the spirit, at least, of Small's interpretations. But we have tried to use tamer animals than he did, and by so doing we have been enabled to improve slightly upon his method. As is well known, Small was the first investigator to show that both the white rat and the wild gray rat can learn the above complicated maze. Small's time records, however, cannot be used as a basis of comparison with those obtained from other animals which have been allowed to form this association. The inaccuracy in his records arises, in the first place, mainly by reason of the fact that he allowed his animals the run of the maze for a whole night before beginning to record the time of their successive trips through the maze. Any one familiar with the habits of the rat knows that ' curiosity ' is the key note of his existence. A new situation means the releasing of a great amount of motor energy. This takes the form of the minute examination of all the surrounding territory. An untrained rat at liberty in the maze is not content with a first success: he tastes the food, leaves it and goes out upon a new exploring tour. He promptly gets lost, finds his way back, tastes the food again and again leaves it. This procedure is kept up until both his emotional state is quieted and his appetite appeased. It is clearly evident that if one adopts a method such as the above, one must relinquish the idea of any accurate statement of the early stages of the process of forming this association. In the second place, Small allowed more than one animal to run the maze at the same time. This in itself is destructive of an accurate time record. Even rats living together in the same cage will take ' time out ' to smell one another in passing. Small's records are unquestionably quantitatively unusable, but the qualitative side of his work is valuable. His work is so recent in the minds of investigators, that we shall not go into it in any great detail.

Remembering that Small is describing only the latter part of the learning process (since all the animals had had the run of the maze for a whole night unobserved), let us quote his

description of the formation of this association by the white rat.[1] "In appreciating the results of this series of experiments, about the same facts come into view, only more distinctly, as in the case of the wild gray rats; the initial definiteness of movement and the fortuitousness of success; the just observable profit from the first experiences; the gradually increasing certainty of knowledge indicated by increase of speed and definiteness; and the recognition of critical points indicated by hesitation and indecision; the lack of imitation and the improbability of following by scent; the outbreak of the instincts of play and curiosity after the edge of the appetite is dulled. In addition are to be noted the further observations upon the contrast between the slow and cautious entrance into, and the rapid exit from the blind alleys, after the first few trials; the appearance of disgust on reaching the end of a blind alley " (Small indulges in a little anthropomorphism here) ; " the clear indication of centrally excited sensations (images) of some kind; memory (as I have used the term) ; the persistence of certain errors, and the almost automatic character of the movements in the later experiments. Viewed objectively, these observations all converge towards one central consideration; the continuous and rapid movements of the rats in threading the maze amounting to almost perfect accuracy in the last experiments. . . ."

Since we are, at the present moment, concerned with the establishment of the norm of the process of learning the maze as a whole, we shall leave the discussion of Small's analysis of the sensory factors entering into the formation of this association to a later place in this report.

Kinnaman's observations of the behavior of two Rhesus monkeys in the maze should next be considered.[2] He constructed a large maze, built on exactly the same plan as the one used by Small with the rats. The dimensions of this maze were as follows: 17 feet long, 13 feet wide, and 14 inches in height. The width of the alleys was one foot. The material used in constructing the maze was common chicken wire. The

[1] *Ibid.,* p. 218 f.
[2] *Am. Jour. Psy.,* Vol. 13, I., 98–148; II., 173–218.

learning process here as with the rats was a gradual one—a good deal more so than that of the rats. Kinnaman arbitrarily decided to regard the maze as learned, when the animals could make ten successive trips without error. In general, the behavior of the monkeys in the maze was like that of the rats; the persistency of certain errors, the rapid elimination of certain others, the increase in speed after the first few successful trials, etc., were all observed. A marked individual (or sexual?) difference was found to exist between the male and the female monkey. In the 13th trip, the female went without error; whereas the male did not parallel this until his 36th trip. The female reached the above arbitrary standard (10 successive errorless trials) of excellence on her 66th trial—the male on his 113th. His movements were faster than hers; he attained to an average time of 44.8 seconds, while the female average never went below 55 seconds.

Kinnaman[1] tries to compare the rate of improvement of the successive trials of the monkeys with that shown by one of Small's rats, but for reasons stated above, the comparison is almost valueless. As far as the comparison of the two time records is at all possible, it shows that the percentage rate of improvement in the two cases is somewhat similar. A more accurate comparison of the absolute rate of improvement of monkey and rat can now be made by taking the results obtained from our own combined records (see page 23). On page 185 of the article referred to above, Kinnaman has given a tabulated report of the maze results of the monkeys. He throws the consecutive trials of the monkeys, separately for the male and the female, into eleven groups of ten and takes the average of each group. For convenience of comparison, we will present the first three group averages of this table (changing seconds into minutes), and throw our own results obtained from the white rat into a similar table. The comparison can be carried out only to the 30th trial, since the rats were not given more than that number.

[1] *Ibid.*, pp. 185–186.

	1st ten.	2d ten.	3d ten.
Male Monkey	12.10	1.22	1.26 Min.
Female Monkey	23.35[1]	2.12	1.06 Min.
Rats	4.49	.68	.42 Min.

On page 186 of the same article, he gives the individual time records for the first ten consecutive trials of the male and of the female monkey (from which the above group average of ten was made). Below, we reproduce these, again changing seconds into minutes, and give for comparison the first ten consecutive trials of the white rat:

1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.	9th.	10th.
45	30	7	3	15	3.8	6.5	4.7	2.6	3.4 Min.
55	132	14	7	6.2	7.5	3.5	3.2	2.7	2.2 Min.
16.20	7.21	7.01	2.90	2.9	2.65	2.09	1.23	1.65	1.06 Min.

Taking the two sets of records at their face value, the monkey isn't ' in it ' when it comes to a race in learning the maze. But we must remember first of all, that Kinnaman's records are based upon two animals. We have found several rats from time to time which could not learn the maze any faster than these monkeys. Under more suitable conditions and with a larger number of animals, the record of the monkey might be materially lowered. In the second place, before any comparison can be made, we ought to know something about the respective speed of the two animals in traversing a labyrinth path. Kinnaman's maze was larger than our own. He gives the length of the true pathway as being 105 feet. The final minimum time for traversing this distance was, as has been stated, 44.8 seconds for the male monkey, 55 seconds for the female. This would make the male's speed in the maze (if it were uniform) about 2.3 feet per second, the female's, 1.9

[1] Attention is called to an error on Kinnaman's part in obtaining the *average time of the first ten trials* of his female monkeys. On page 185 of the article referred to he gives this average as being 2,579 seconds. If one refers to page 183 one finds that the times of the first ten individual trials which were averaged read as follows:

| 3,300 | 7,920 | 840 | 420 | 375 | 450 | 210 | 195 | 165 | 135 sec. |

The average is 1,401 sec., or almost one-half the time as given by Kinnaman. This error serves to vitiate all the percentage values of the female's record, etc., which were made upon the basis of the average of her first ten trials.

feet per second.   The length of the true pathway of our maze
is forty feet.   The final minimum time consumed by the rat
in traversing this distance at the end of 30 trials is on the
average about 20 seconds (many of our rats after having 50
trials can run the maze in ten seconds.   The minimum record
in the laboratory is nine seconds).   This makes his speed in
the maze about 2 feet per second.   If Kinnaman's times for
the monkeys are at all representative, it would appear that the
final rate of the monkey is about the equal of the rat's at his
30th trial.

Porter[1] has made similar experiments upon the English
sparrow.   The learning process with the sparrow is similar
to that of Small's rats and Kinnaman's monkeys.   Porter
makes a detailed comparison of the rate of learning between
the monkeys and the sparrows.[2]   He likewise throws the con-
secutive trials of one female sparrow into groups of ten and
averages them.   These averages of the group records are
given below (in minutes).

	1st ten.	2d ten.	3d ten.	4th ten.	5th ten.	6th ten.
English sparrow	8.2	6.2	1.8	1.2	.92	.56 Min.

Porter gives separately the record of the first ten consecu-
tive trials of two females and one male.   We have ventured
to average these, thinking that we should obtain a more typical
record thereby.   This average record of the first ten consecutive
trials of the sparrows follows immediately:

1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.	9th.	10th.
36.1	19.2	11	8.4	2.6	3.1	4.3	2.3	5.1	6.6 Min.

Porter states that his maze was exactly one-half the size
of Small's.   The true pathway of Small's maze measures ap-
proximately 50 feet (so Professor Sanford kindly tells me),
that of the Porter maze then should measure 25 feet.   The
sparrow's final minimum time of travelling this distance is
33.7 seconds, consequently his speed in the maze is approxi-
mately 1.3 feet per second.   If we make allowances for this
difference in speed which is probably due to structural causes,

[1] *Am. Jr. Psy.*, Vol. 10, pp. 313–346.
[2] P. 339 ff.

the sparrow's minimum time is proportionately equal to that of the rat. (If the distance were made proportional to the speed, the length of the true pathway of the rat's maze should be 38 feet which is almost the length of our own maze—$1.3 : 25 :: 2 : x$, so $x = 38$ feet). It is rather singular that the two mazes should have been constructed so nearly proportional to the respective speeds of the two animals. If we turn to the absolute rate of learning of the two animals (cf. first ten trials of sparrows and rats) we notice that the sparrow's time records are very much inferior to those of the rat. But again, we must bear in mind that the number of sparrow records like those of the monkeys is too limited to enable us to draw any kind of safe conclusion.

The maze in its simpler forms has been presented to several different kinds of animals—Yerkes[1] experimented upon the green frog, Yerkes and Huggins[2] upon the crawfish, Triplett[3] upon the perch, Watson[4] upon the white rat, Allen[5] upon the guinea pig, Porter[6] upon the English sparrow and other birds, Rouse[7] upon the domestic pigeon, Fielde[8] upon the ant, etc. In so far as the above-mentioned investigators contribute anything towards the possibility of the analysis of the sensory factors entering into this association, they will be discussed in detail under Part B, a, page 25. Many interesting facts bearing upon the learning of the maze as a whole have been brought out by these comparative tests upon the different animals; such as the degree of complexity of the maze which a given animal can learn; the absolute and relative time records; the percentage rates of improvement, etc., but the separate consideration of these facts would take us too far afield.

[1] *Harvard Psychological Studies*, I., p. 579.
[2] *Harvard Psychological Studies*, I., p. 565.
[3] *Amer. Jour. Psychol.*, 1901, XII., pp. 354–360.
[4] *Animal Education*, p. 59 ff.
[5] *Jour. Comp. Neurol. and Psychol.*, Vol. XIV., 1904, pp. 293–359.
[6] *Amer. Jour. Psychol.*, Vol. XVII., No. 2, pp. 246–271.
[7] *Harvard Psychological Studies*, II., pp. 581–613.
[8] *Proceedings of the Academy of Natural Sciences of Philadelphia*, 1901, pp. 521–544.
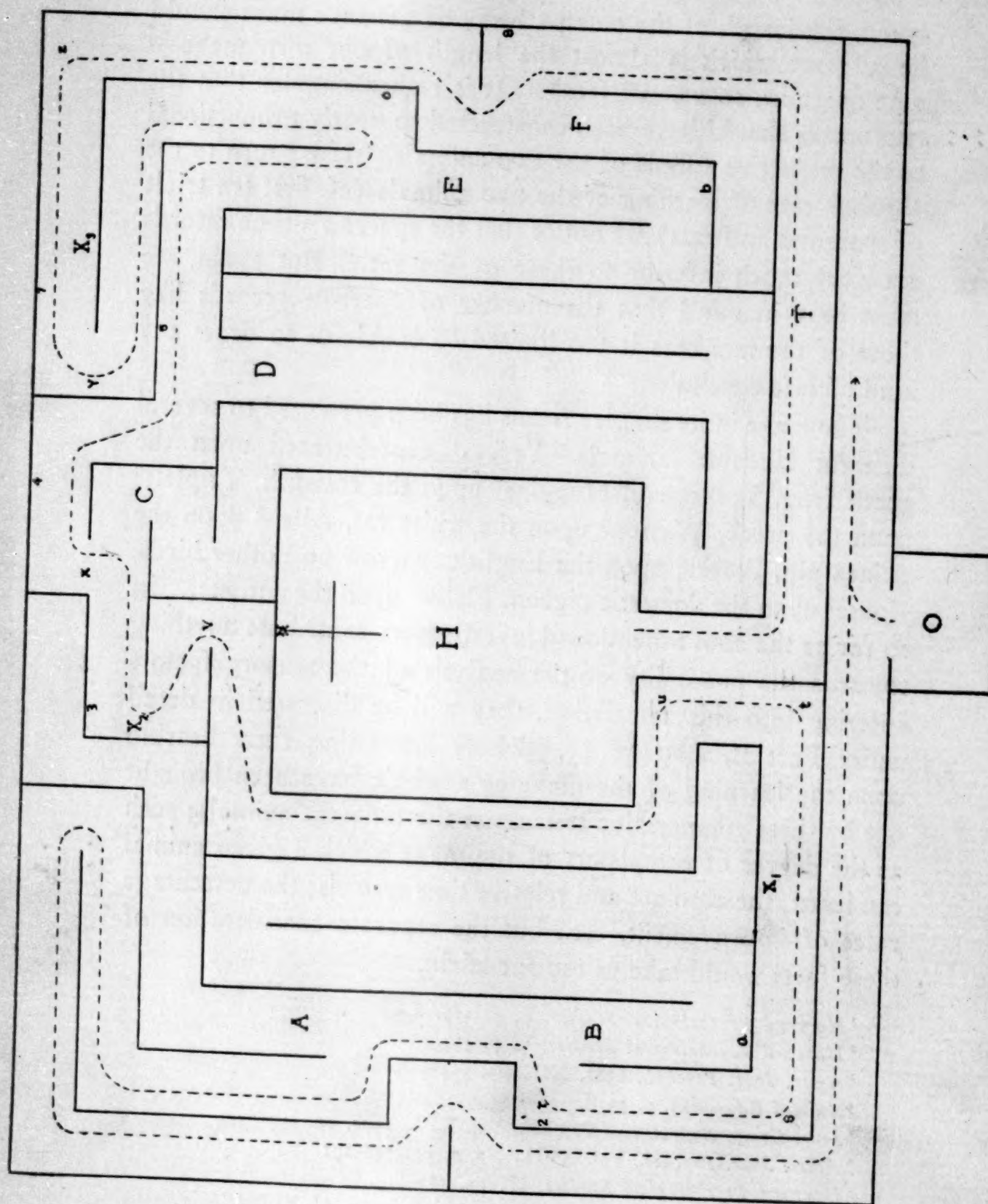
FIG. 1. Plan of maze used in all the following experiments. (Adapted from Small.)

(c) The Description of the Maze, and the Method of Experimentation Used in the Present Investigation.

The same maze was used in all the experiments which follow. The bottom of the maze and the sides of the galleries were made of wood ⅞ of an inch thick. The top of the maze was of wire netting, ¼ inch mesh. The plan of the maze was a duplicate of the one used by Small in his investigation at Clark University,[1] except that the dimensions of the ground plan of his maze were 6 by 8 feet, while those of ours were 5 by 7 feet. The dimensions of the galleries in our maze, however, were exactly the same as in his. This means, of course, that our central food-box was smaller than that of the maze used at Clark. The distance from the entrance of the maze to the central food-box was 40 feet. This distance is represented in Small's diagram by the broken line. It is then a measurement of the approximate route which the rat is forced to take in rounding corners, etc. As before stated the actual measurement of this distance on the maze at Clark is about 50 feet. The true pathway in our maze is shorter then than that of Small's maze by 10 feet. Since our rats, when trained to the maze, covered this distance in about 20 seconds (at the end of 30 trials), their rate of movement is about 2 feet per second. This makes it possible, by adding 5 seconds to any of our individual time records to make them absolutely comparable with those obtained by some other investigator observing the behavior of rats in a maze of the exact dimensions of Small's.

In front of the entrance to the maze, *O* in our diagram, a box 8 inches wide, 11 inches long and 4 inches deep was nailed to the maze. This was covered by a hinged wire top. This box afforded a convenient way for admitting the rat to the maze.

The main difference between the two mazes lies in the materials used in their construction. The one adopted by Small was made throughout of wire netting. This permits an animal to see from one gallery to the next. In our maze,

[1] *Am. Jr. Psychology,* Vol. 12, p. 207 ff.

this was impossible.   What influence this fact may have upon keen-sighted animals is not known: That it makes little or no difference in the case of the rat, the sequel will abundantly show.

The method of conducting the experiments here reported (and this applies to Dr. Carr's experiments as well as to our own), was as follows: A quiet time of the day was chosen for conducting the work—9 A. M.–12 M. in our own series, 4 P. M.–6 P. M. in Dr. Carr's.   Food was placed in the central food-box.   This food consisted usually of a saucer of milk-soaked bread.   By the side of this dish, a small piece of cream cheese was placed (the higher the cheese the better!).   A large piece of fresh-toasted cheese was placed on the outside of that part of the wire netting which served as a covering for the maze, immediately over the center of the food-box.   This larger mass of cheese served the purpose of increasing the intensity of the stimulus.

The particular animal whose record was desired was placed in the little box leading to the entrance of the maze, and enclosed there.   He would usually smell the floor and corners of this box for a time (even though trained to the maze) before passing into the gallery.   His time was taken with a stop-watch from the moment he entered the maze until the food was reached.   He was allowed to eat of the food for a short time[1] after which he was taken out, stroked for a few minutes, then tried again.   Usually four trials were given in this way.   Sometimes when the animals reacted well, five trials were given (rarely six).   On the other hand, if the animals were not in good condition (even when every care is taken as regards the amount of food given the day before, etc., this will occur) only one reaction was taken.   A diary record, showing the number of trials taken each day, the exact number of hours elapsing between any two sets of trials, the number of errors, etc., was made.   These minute records, however, are not reproduced in the tables shown in this paper.   In our own experiments the rats were observed *every day*.   If this was not done, the animal was likely to get out of the ' swing,' and his

[1] See Watson, *Animal Education,* p. 9.

first time record after a day or two without experimentation was likely to be too long.

After the animal had finished his set of reactions for the day, he was allowed to eat freely of the milk-soaked bread. When he showed signs of satiety, which he manifested by beginning to ' explore,' he was removed to his living cage and fed no more until tested in the maze on the following day. Utter hunger was thus avoided. Our rats, on the whole, have been in *better physical condition* during the period of experimentation than when they were allowed to live quietly in their cages. This has been emphasized, much to our sorrow, as we write the present paper. For two months, our rats blind, anosmic and normal have been idle. At the present moment, all of them are in poor shape. When we finished our experiments upon them, they were in perfect condition. Much has been writen about the artificiality, the abnormality—yes, even the brutality of the present 'laboratory'. method in animal psychology. However well founded they may be in certain cases, these criticisms cannot with justice be urged against the present set of tests.

In our experiments upon the ' normal control series,' a cumulative stop-watch was used. When an animal stopped to scratch, or to bite at some particle in the maze, the time used in the process was taken out. This time, however, was found to be insignificant after the first few trials of the rat. When we found that the records taken on the blind and on the anosmic rats were likely to be better than those of the normal control, we abandoned the use of the cumulative watch, for fear some one might think we had unconsciously (!) helped the animals' records a trifle. All of Dr. Carr's experiments were timed by an ordinary continuous stop-watch.

There is one serious defect in the Small maze. We find it impossible to take an accurate account of the errors in it. As a matter of fact, we have recorded the errors made by our rats the way suggested by Small, Kinnaman and Porter. They fill one or two note-books, but we feel sure that they are not worth the time we spent in recording them—certainly are

not valuable enough nor accurate enough to publish. Since this position makes the absolute time record the only criterion of the learning process, we have used extra precautions to make it show what it is meant to show, viz., the relative rapidity with which normal and defective rats form the maze association. We have both time and error records before us, and we unhesitatingly say, that the time record, carefully controlled, is the only safe guide in estimating the learning process of a maze constructed along the lines of the present one.

In these experiments on the normal and blind rats, no effort was made to rule out the help which smell might give the untrained rat in the form of *tracking*. Small covered the bottom of his maze with fresh sawdust, and changed it each time a new rat was introduced to the maze. But since Small concludes that smell in the sense of tracking plays little or no part in the formation of this association; and since this conclusion is in agreement with the results of some experiments which we made upon the white rat some years ago,[1] we decided to neglect this possible source of error. In view of the fact that our previous work shows that the element of tracking is possibly present when males and females are both traversing the same pathways, male rats were used in most of the experiments in the present series. The two anosmic females observed are exceptions, but here, fortunately, since smell is ruled out, the exception makes no difference. However, their records are shown separately.

In concluding this section, it remains to be said, that all of the animals used in this work were exceedingly tame. In addition to the fact that they were pets to start with, they were fed in the food-box of the maze each day for a week before they were allowed to learn the maze. They were, of course, strictly confined to the food-box, and were not allowed to traverse any other part of the maze. This causes the animal to become accustomed, (1) to obtaining his food in the maze, (2) to the noises necessary in opening and closing the maze, and, (3) to handling. The benefits accruing from this method were not

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[1] *Animal Education,* p. 53.

fully appreciated until after the normal control series had been taken. The animals used for obtaining this record had not received the proper amount of this preliminary experience before their reactions were taken. Undoubtedly, this makes their time averages for the first few trials too high. Fortunately, the ' combined ' record and Dr. Carr's records control the defects in our own.

PART A.

The Results of Experiments Upon the Behavior of Normal Rats in Learning the Maze.

(a) *Experiments Upon Four Rats to Establish a Normal Control Series.*

Since the main facts in the present paper are concerned with the comparison of the behavior of the normal rats in learning the maze, with that of animals having defective sense-organs in forming the same association, the first step to be taken is to establish a normal record of the learning process. This is all the more imperative, since, as we have mentioned above, Small's time records are unusable. But since Small has so adequately and so minutely described the qualitative features of the behavior of the gray and white rats in their later reactions to the maze, we shall pass over the description of the details of the formation of this association, saying a few specific words, however, about the early stages of the learning process.

In the fall of 1905, four male rats about one year of age were started upon the problem of learning the maze mentioned above.

In general, the behavior of these rats in the maze may be described by the following statements: The first few trials in the maze are characterized by the making of every possible error. The food at first apparently exerts little or no influence in drawing the animal to the food-box. The stimulus of the new surroundings is more potent and the animal's ' attention ' roves freely from one part of the maze to the other. This type of behavior stands out in bold relief against that of the fully trained animal. In the latter case, the food is the emotionally exciting object. It compels his attention from the start and retains its power to the end.

One very peculiar type of error was made by all of our rats in the beginning of the experiments, viz., that of ' back-

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tracking.' The rat first becomes emotionally neutral to his starting point, *i. e.,* the small box at the entrance to the maze, to which he always has access. His first movements away from this neutral position do not carry him any great distance. He then returns to the starting point—his second advance usually carries him farther than his first. This process of advancing and retreating, making errors all the time, ends finally in his *learning* the maze *backwards* by the time he has learned it forwards.[1] We emphasize this point especially because many have thought it strange that the rat could get back from the center of the maze without ever having had his food stimulus at the opening to the maze, and his starting point at the center. We have seen our rats make several errors in going towards the food-box; getting almost there, they would run into the last possible cul-de-sac, come out, take the ' back-track ' and come rapidly home without an error. The causes for this behavior are to be sought for undoubtedly in the emotional condition of the animal. While it is not true of the very young animals, it is true of these four adult males, that the maze undoubtedly stirred the emotion of fear in them. This was especially true of one rat—the one which gave the maximal time in Table I. (p. 19). His behavior was so marked that it deserves mention. He hugged the sides of the galleries and both advanced and retreated by furtive dashes. This was true, notwithstanding the fact that he was perfectly tame when held in the hands. We feel sure that the stimulus to the learning of the pathway back to the entrance lies in the ' at home ' or ' of course ' mood which, being produced there, brings relief from emotional excitement. (It must be remembered that our rats, once reaching the food-box, were not allowed to run back. They were allowed to get to the food-box the best way they could, by running backward or forward, etc., but once there, they were restrained from leaving it until a new trial was started.)

After the first success in the maze, the absolute *time* of the

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[1] This is not quite true! Dr. Carr made a series of tests upon trained animals by putting the food at *O* and starting the rat at *H*. It took the rats 2½ trips on the average to become perfect after this reversal of the pathway.

succeeding trials is often reduced before the number of errors is reduced. The animal is more active because the food has become a specific stimulus. This state of affairs may continue for several trials. The first signs of the decrease in the number of errors are to be found when the animal ceases to run the full length of the cul-de-sacs—he makes the initial error, *i. e.*, by leaving the true pathway, but he no longer follows his error out to the bitter end. He will often turn in the middle of a cul-de-sac and retrace his steps to the true pathway. (This is the stage marked by Small, when he says they turn showing apparent signs of disgust.)

The second stage in the process of decreasing errors, is marked by the animal's showing simple *hesitancy* at the turns. As long as the track is straightaway, there is ' full steam ahead '; the moment a turn is reached, a slowing of the speed of the animal is noticeable. Sometimes his momentum actually carries him beyond the correct turn. A full stop is then made, and the animal retraces his steps and turns into the true pathway. As is expressly stated by Small, Kinnaman, and Porter, the various possibilities of error are not equalized; some errors are persistently adhered to, while others are rapidly overcome.

From this point on, the hesitancies become of less and less duration, and they are made at fewer and fewer places. Finally the animal becomes a veritable automaton. At this stage, the time becomes practically constant and is reduced almost to the actual reaction-time of the animal in traversing a tortuous pathway, 40 feet in length.

Table I. and the curve constructed from it (Curve I.) show the details of the average times of the first and succeeding trials of four normal rats in the maze. Table I. shows in addition the maximum and minimum times at any given trial. The maximum and minimum times are individual records, of course. They are not always taken from the same rats in the various trials. It may very well happen, and often did happen, that the *maximum* time on the 7th trial, for example, was made by the rat which gave the *minimum* on the 5th trial.

TABLE I. Showing the *average*, the *minimum* and the *maximum* times of four adult male rats in learning the maze. (Normal control series.)

No. of Trial.	Average. Minutes.	Minimum. Minutes.	Maximum. Minutes.
1	29.01	6.28	87.41
2	10.59	5.56	23.46
3	12.31	2.31	31.31
4	3.80	2.46	5.44
5	4.42	2.33	8.70
6	5.01	2.21	5.44
7	5.15	1.75	8 21
8	2.12	.65	5 30
9	2.24	1.00	5.05
10	2.09	1.06	3.08
11	1.86	41	4 71
12	1.60	.32	3.76
13	1.17	.33	2.98
14	1.65	1.20	2.63
15	1.08	.36	1.98
16	.63	.25	1.23
17	2.86	.68	8.46
18	1.06	.55	2.38
19	.76	.35	1.48
20	.95	.48	1.55
21	.42	.28	.55
22	.79	.53	1.45
23	.67	.43	.91
24	.68	.30	1.41
25	.57	.30	.90
26	.55	.28	.91
27	.72	.35	1.18
28	.49	.25	.96
29	.56	.25	.86
30	.45	.23	.65
31	.51	.23	.98
32	.46	.31	.78
33	.38	.31	.41
34	.38	.23	.58
35	.42	.25	.78
36	.31	.20	.45
37	.29	.23	.33
38	.35	.25	.43
39	.44	.28	.81
40	.30	.26	.38
41	.31	.23	.40
42	.41	.25	.61
43	.38	.23	.55
44	.37	.22	.55
45	.31	.21	.51
46	.27	.23	.33
47	.26	.23	.33
48	.26	.20	.38
49	.28	.20	.46
50	.30	.18	.50

A separate and detailed discussion of this table and its accompanying graph is not necessary. It shows the relatively long time of the first trial and the rapid decrease in the time

of the succeeding trials—the time of the 19th trial falling below one minute and remaining lower than that for all the succeeding trials.   This time record of the normal rats in the maze is by no means an unusually low one—in fact, from the experiments of our students and later ones of our own, we are inclined to think that it is somewhat too high to be really representative.   We have already stated, however, that these rats
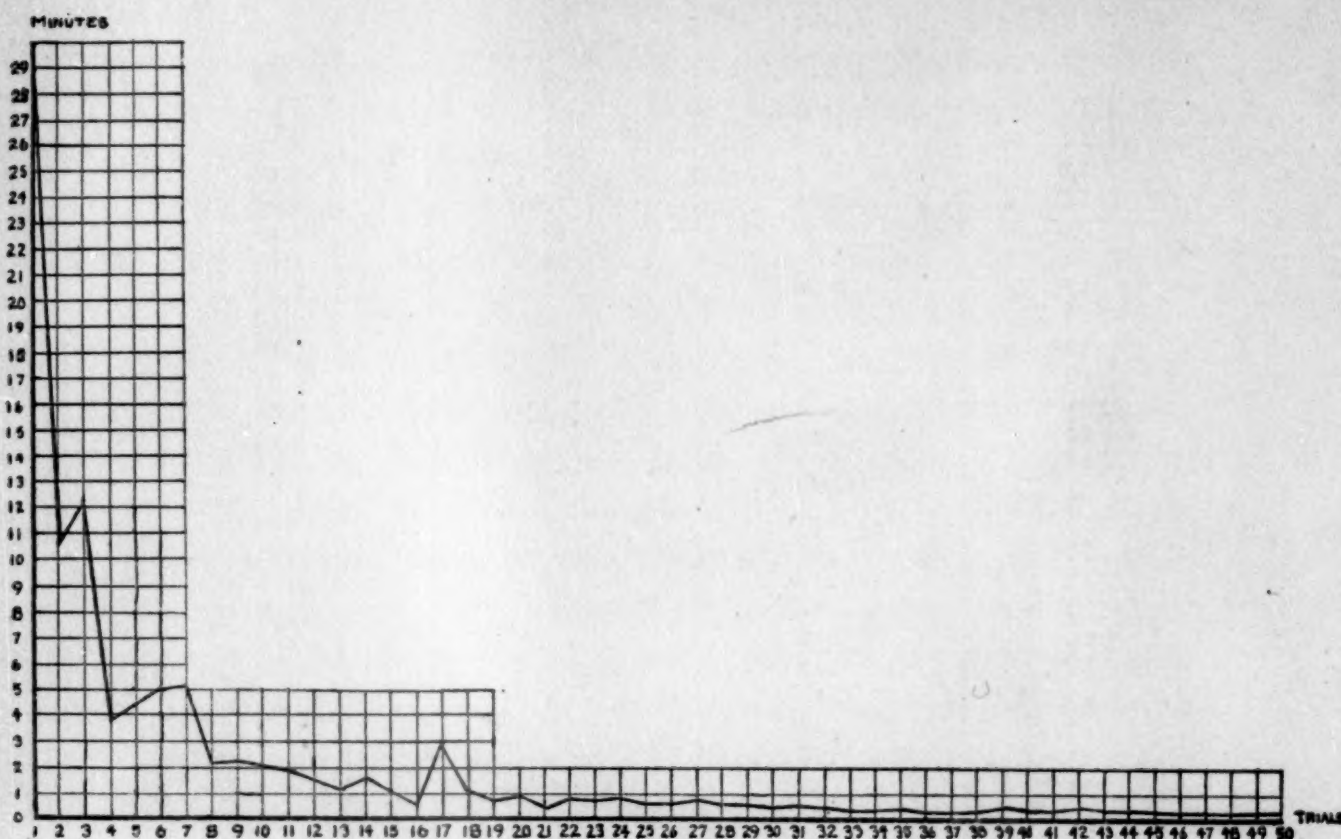
CURVE I.   Showing the normal process of learning the maze.   Based upon four normal male rats, about one year of age.   In all of the following curves one division of the ordinate represents one minute, while one division of the abscissa represents one trial.

were one year old, and that they were more timid in the maze than any of the other rats with which we have experimented. The possible influence of the age of the animal upon the time of the formation of the maze association will be further discussed in the section immediately following.

(b) Preliminary (Unpublished) Experiments Made by Dr. Harvey Carr.

Dr. Harvey Carr, working in this laboratory in the spring of 1905, observed a number of very young rats in the act of

forming this association. The record of his experiments on three of these rats (35 days of age at the beginning of the experiment) are tabulated in Table II. and are shown graphically in Curve II.

TABLE II. Showing Dr. Carr's experiments on the learning of the maze by three very young rats.

No. of Trial.	Average. Minutes.	No. of Trial.	Average. Minutes.
I	9.76	15	.44
2	22.50	16	.53
3	3.70	17	.33
4	3.46	18	.45
5	2.08	19	.48
6	1.58	20	.48
7	1.30	21	.49
8	.99	22	.26
9	1.15	23	.33
10	1.05	24	.30
11	1.02	25	.33
12	1.55	26	.35
13	.41	27	.50
14	.51	28	.30
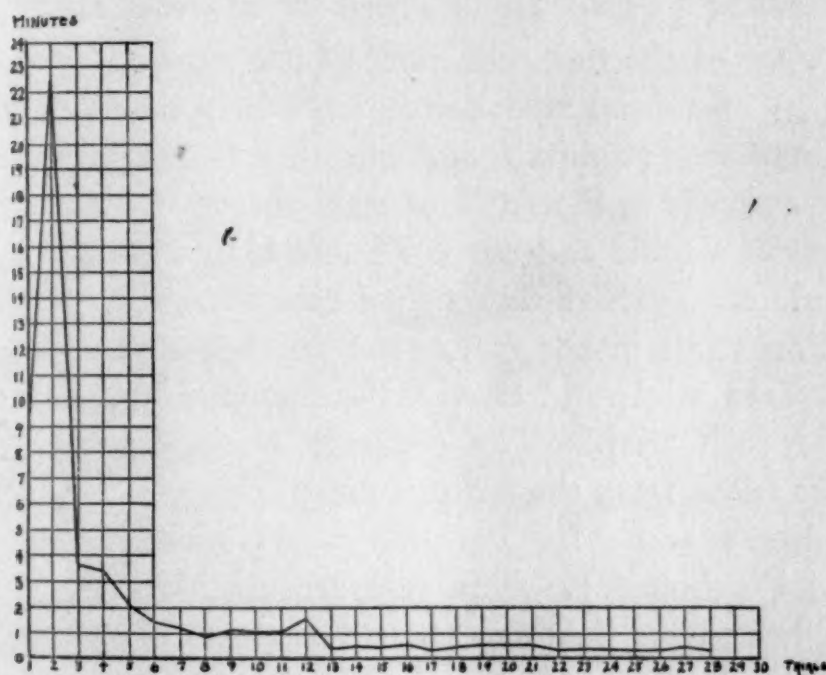
CURVE II. Showing the normal process of three young rats in learning the maze. The rats were about 35 days of age at the beginning of the experiment.

The above is undoubtedly a very remarkable record. If one compares it with our own just reported, one cannot fail to be struck by the fact of the greater rapidity of the learning process of the young rats. After the second trial, the average

time drops below 4 minutes and constantly grows smaller, until on the 13th trial the average falls below one minute (the 19th trial marks the corresponding point in our own series). In addition to this more rapid shortening of the time in the first few trials, we notice that the average of the last five trials, from the 24th–28th inclusive (Dr. Carr's records extend only to the 28th trial) is .37 min., while this average is not reached by our rats until the five trials lying between the 33d–37th. Although the number of animals in the two cases is too limited for any generalization, we feel sure that the apparent differences, as shown by the above records, between the rapidity of the learning process in the young and in the old rats would be confirmed by a more extended series of experiments. The factor of age is undoubtedly of importance whenever a comparison of any two records is desirable.[1]

(c) *A Combined Record of the Time of the Learning of the Maze (Based Upon Nineteen Normal Rats).*

In view of the fact that most of the curves illustrating the formation of animal associations have been based upon a very limited number of animals, and inasmuch as a certain theoretical interest attaches to the form of such curves, we have ventured to construct a table and curve (Table III., Curve III.) which will show the average time of 19 rats upon their 1st, 2d and succeeding trials in the maze, the average mean *variation* in time at each trial; and finally, the maximal and the minimal times at each trial. The separate records going into this table are taken from the writer's experiments, Dr. Carr's, Miss Richardson's and Mr. Peterson's (Fellows in the Department of Psychology). The data are not ideal by any means. In the first place, they are taken from rats of different ages; from rats not all of which have had the same previous experience with other problems; from three rats which were given *one* trial each day, whereas all the other rats were given 3, 4 or 5 trials each day; and finally, from both male and female rats. But notwithstanding this apparent heterogeneity in the sources of the data, we feel sure that the *form* of the curve is

[1] Cf. *Animal Education,* p. 84.

not altered by these differences—the effect of ideal conditions would probably be felt only in the lowering of the absolute time of any given trial.

TABLE III. (Curve III. is inserted at end of paper.) Showing average time, average mean variation, maximal and minimal time, and percentage decrease in time of 1st, 2d and succeeding trials. (Based upon 19 normal rats.)

No. of Trials.	Average. Minutes.	Mean Varia-tion. Minutes.	Maximal. Minutes.	Minimal. Minutes.	Percentage.
1	16.20	12.08	87.41	1.36	100.0
2	7.21	5.69	40.00	.93	44.5
3	7.01	5.63	31.31	.41	43.2
4	2.90	1.34	6.00	.25	17.9
5	2.90	2.15	9.00	.28	17.9
6	2.65	2.11	10.41	.31	16.3
7	2.09	1.43	8.21	.33	12.9
8	1.23	.80	5.30	.23	7.5
9	1.65	1.26	5.41	.33	10.2
10	1.06	.61	3.08	.21	6.4
11	.90	.59	4.71	.31	5.5
12	.90	.66	3.76	.21	5.5
13	.67	.44	2.98	.25	4.1
14	.84	.59	2.73	.16	5.1
15	.64	.34	1.98	.18	3.9
16	.46	.23	1.20	.22	2.8
17	.51	.24	1.58	.17	3.1
18	.59	.29	2.38	.18	3.6
19	.59	.32	1.48	.20	3.6
20	.70	.40	1.95	.17	4.3
21	.51	.29	1.83	.15	3.1
22	.43	.20	1.45	.17	2.6
23	.48	.30	2.00	.16	2.9
24	.48	.26	1.41	.18	2.9
25	.39	.18	.90	.16	2.4
26	.41	.20	.91	.19	2.5
27	.46	.23	1.18	.16	2.8
28	.35	.14	.96	.17	2.1
29	.35	.14	.86	.18	2.1
30	.39	.12	.65	.18	2.4

The form of this combined curve has theoretical interest in view of Hobhouse's criticism of the conclusions drawn by Thorndike from the curves illustrating the learning processes of his dogs, cats, chicks and monkeys. Thorndike states that the method of learning in these animals is a gradual one of 'trial and error'—corresponding, therefore, more or less closely to Hobhouse's method of learning by assimilation. Hobhouse states that Thorndike's curves do not show a gradual learning process—'unless a steeple tower' can illustrate such a method. In view of the nature of the maze problem, and the rats' method of learning it, viz., without the aid of any

extra-organic sensory data (the justification for this statement will be found in our 'conclusions'), it is hard for us to see how the learning process could be any other than that of trial and error, or that of 'assimilation.' Indeed, we cannot believe that even a human being in the possession of all his thinking faculties, if forced to learn the maze under conditions identical with those maintained for the rat, could learn it in any other way than by the slow acquisition (it would be exceedingly slow at that) of a motor habit. And yet, if we turn to our combined curve for the rats, we see that it, like Thorndike's, possesses the 'steeple tower' appearance; but to our minds, this does not militate against the view that the rats' method of learning this problem may be a 'gradual' one. We would account for the 'steeple tower' appearance of our curve by appealing, 1st, to the facts concerning the emotional condition of the rats in their first few trials in the maze, and 2d, to the lack there, at first, of a specific and controlling stimulus. The first point needs no elaboration. In regard to the second point, we have in mind the fact that in the beginning of the learning process, the maze as a whole offers no such stimulus as it does later, after the animal has 'learned' that food is at the 'other end of the line.' On the contrary, the maze offers at first what, for lack of a better term, we may call 'part stimuli': The rat's 'attention' is distracted by the various odors, contacts, etc., at every corner of the maze. The learning process as a whole may be looked upon as the *establishment of a stimulus;* and, as far as we can see, this process of establishing the maze as a specific stimulus *need not necessarily be a gradual one—i. e.,* the first two or three trials might be most effective in overcoming the initial neuro-muscular inertia. This might be true, and still the mental process involved in the learning of the problem might not rise above the level of the 'method of assimilation.' On the whole, we feel that Hobhouse's position with reference to the form of Thorndike's curves is not well taken.[1]

[1] We realize, however, that the above statements of ours are summary and more or less dogmatic. Our defense lies in the fact that the complete theoretical discussion of the form of the curve necessary to illustrate the trial and error method of learning would require a paper devoted to that topic alone.

PART B.

ATTEMPTED EXPERIMENTAL ANALYSIS OF THE SENSORY FACTORS ENTERING INTO THE FORMATION OF THE MAZE ASSOCIATION.

I. *Historical Survey and Report of Some Unpublished Preliminary Experiments.*

(*a*) *Review of Results Obtained by Other Investigators.*

Small, it is of interest to note, although one of the pioneers on the maze problem, is the investigator who has gone farthest in the attempt to show experimentally the number and the complexity of the sensation processes involved in this form of association. Kinnaman and Porter, both of whom used a maze built on the plan of Small's, seem to have been interested mainly in the fact that their animals had the ability to form this association. Kinnaman does not state whether his monkeys could run the maze in the dark after having previously learned it in the light. Porter would have had difficulty in making his sparrows work in darkness, but the monkeys very probably would have had no such scruples.

Turning to the details of Small's investigation, we find[1] him making the following statements: " The sense of smell might be supposed *a priori* to play the leading rôle, but in the present case its claims to priority are doubtful. In the preceding section, it has been shown that the location of the food by odor, and hence the end to be reached, was an important factor. . . . In general, animals perceive direction of odors only with the aid of air currents. The perception is quite as much tactual as olfactory. It is even clearer that the trail of the first accidental success was not followed subsequently by scent. In the first trial, the rats invariably traversed practically all of the galleries, and, after appeasing their hunger a little,

[1] *Am. Jr. Psy.*, Vol. 12, p. 232.

carefully investigated the entire maze. It would be impossible, therefore, for them to select the right path by scenting the trail. Again, the second rat frequently turned aside from the route marked out by his immediate predecessor. . . . Further, the recognition of critical points, and the fact that the rats frequently ran long distances with heads up—*e. g.*, when carrying food—are evidence against this supposition. . . .

" Another possibility in regard to smell is that particular points in the maze may have been associated with definite peculiarities of odor. The constant sniffing and extensive olfactory investigations of the rats lend color to this thought. The experience thus acquired may, however, influence only the affective tone—connect directly with the emotional tendencies which determine the animal's conduct. . . . The inference is clear that the effect of smell sensation is general and emotional, rather than that delicate and discrete associations of odors with special positions are set up. The point is, however, not absolutely secure. Probably more conclusive evidence might be obtained by testing rats with olfactory nerves paralyzed."

These sentences just quoted from Small's paper are undoubtedly very accurate statements of the inferences one must draw in observing the behavior of normal rats in the maze.

Having (inferentially) ruled out smell as a *cognitive* factor in the formation of this association, Small summarizes the results of his experiments upon vision. We will again quote from the articles referred to:[1] " As the rats did most of their exploring in the dark (*see criticism of Small's method above*), and as the brightness element is only one factor in the visual datum, not the total datum as with the insect, it was improbable that this factor (*of the direction of the light*) (italics ours) should be very influential.[2] Nevertheless, it was made as a matter of experiment. Tests were made by having the

[1] *Ibid.*, p. 234.

[2] If Small means to imply here that the rat discriminates colors as well as brightness, he is using his imagination! There are no experiments discussed in the literature of this subject which show that the rat reacts to colors apart from their brightness. For six months, Mr. and Mrs. Hayes (whose results, it is hoped, will shortly appear), working in this laboratory, have attempted to get unequivocal results upon this very point.

rats learn the path perfectly with the direction of the light constant. The light was then transferred to the opposite side for a few trials, after which it was alternated at unequal, though frequent intervals. The results were: (1) In most cases, change of the direction of the light seemed to produce a very slight effect upon celerity and certainty of movement, but hardly more than might occur as normal variation under constant conditions. (2) Some subjects showed absolutely no effect. (3) After the first change, the alternation produced no effect."

However much we may be inclined to accept Small's bare statement on this particular point of the influence of the direction of the rays of light, we should have been indebted to him if he had given us a record: (1) of the number of rats used; (2) of the time of the trials immediately preceding the change in the direction of light; (3) of the time of the trials immediately subsequent to the change. As a matter of criticism, we may say that the method of learning in the first place—that of allowing the rats to run the maze all night without record of their movements—is wholly prejudicial to any later experimentation in the light.

A second set of tests was devised by Small to find the part played by vision in the reactions of the rat to the maze at all critical points.[1] " Bright red posts, one-fourth inch in diameter, were placed in the middle of the right path a few inches beyond the dividing of the ways. When the rats had learned the path perfectly, the posts were removed. Two rats were tried, the results being *nil*. These rats did not learn the path more quickly; nor did they exhibit the slightest variation in conduct after the posts were removed."

The criticisms upon this method are obvious: In all probability, the rats react mainly to gross changes in *brightness*. Reactions to colored reflected light, under ordinary conditions, at least, are of the vaguest kind—*if they exist at all.* This statement as it stands is dogmatic but it is again based upon the results of the observations made by Mr. and Mrs. Hayes.

[1] *Ibid.*, p. 234.

Still another group of experiments was made by Small upon blind rats. These experiments and the results from them will be stated in Small's own words:[1] "A number of my rats came to me with diseased eyes. Before I discovered this, two of them, an adult male *X*, and a young female (about ten weeks old) *Y*, had become blind. I had already started them learning the maze, with two others, when I noticed their blindness. After the fifth experiment, they were totally blind. In the first two experiments, distinct impressions—if white rats have such—may have been possible to *X*; and brightness sensation until the fifth. Rat *Y* may have had brightness sensations in the first two experiments, but not later. At this time, the general health, vigor and temperament of these rats were unaffected by their malady."

Before discussing in detail the behavior of these blind rats in the maze, let us venture a word of remonstrance against the above inferences as regards the degree to which these defective rats could see. From our own observations on the vision of these animals, we feel that it is impossible to make the above sharp distinctions, as regards the very trial at which the rats became blind, and in what trials distinct impressions became indistinct. In the first place, it is next to impossible, we shall go further, it is *impossible* to tell when a white rat is blind, if he possess the organ of vision at all. Many times, we have taken our normal rats with their eyes adapted to darkness, and have flashed strong lights into their eyes—we have never got the *slightest quiver* of an *eye-lash* by so doing, much less a reaction of the rat as a whole. This is far from saying that the rats do not sense the light, but it is strong evidence against naïvely assuming that we can easily determine just the moment when our rat becomes blind, or that he is blind at all. Again, we have extirpated both eye-balls from many rats: After they recover it is difficult to tell any difference between their reactions and the reactions of the normal rats. In order to make this point more secure, we asked Professor Angell into the laboratory as a 'disinterested party.' We put three blind rats and

[1] *Ibid.*, p. 235.

two normal rats upon a large table and asked him to tell the difference in the behavior of the two groups. After an hour's observation, he stated that the difference was practically *nil;* that there was possibly a slightly stronger tendency on the part of the blind rats to rear up on their hind legs.

Small does not tell us of a single test which he made to prove his statements. But to return to the behavior of these defective rats: To be concise, they learned the maze; learned it perfectly, with as few trials and with as few errors as did the normal rats.

Small concludes from these experiments that " sight certainly is not a *sine qua non* in the process of experimental reasoning incident to these experiments."[1]

These are essentially the data by means of which Small arrives at the conclusion that the tactual-motor sensations are the important and only necessary ones used by the white rat in the recognition and discrimination of the important points in the maze.

Kinnaman, whose work on the monkeys in the Small maze has already been discussed, contributes very meager data towards the analysis of the sensory factors entering into the monkey's reactions to this form of problem. Beyond the bare, vague statements which he makes, viz., that the sense of smell is not acute (which he doesn't prove) and that the monkeys rely almost exclusively upon the sense of vision, one searches in vain for any kind of answer to the question.

Porter, in his tests upon the English sparrow in this maze, makes no express statements concerning the sensory factors used by them in the association. The inference to be drawn from his work as a whole, is that vision, in all ordinary reactions, is the sense most depended upon. Whether the sparrows or the monkeys could run this maze in the dark after being trained to it in the light, or whether they could *learn* it in the dark are points which are not touched upon in either of the papers referred to.

Some interesting efforts have been made to determine the specific sensory factors used by the different animals in the

[1] *Ibid.,* p. 236.

learning of the various simpler mazes. Yerkes,[1] in testing the green frogs in simple labyrinths with colored walls, found that the visual impressions received from the different colored walls, the slight differences in brightness of illumination due to shadows from the partitions and the contrast in form of the two sides of the labyrinth resulting from the use of the partitions, and the *muscular sensations dependent upon the direction of turning* were the important sensory data contributing to the establishment of the association. (" The experiments proved beyond question that vision and the direction of turning were the all-important factors in the establishment of the habit.") Yerkes goes on to say, that he had at first thought that the *direction of turning* was the chief determinant in the learning process, but since he found that by altering the visual conditions in the maze, the frogs' behavior was so markedly changed, he came finally to the conclusion that visual data contribute largely to the solution of the problem. Yerkes was also able to show that the tactual sensations and the organic sensations are contributory.

Yerkes and Huggins[2] make the following statements about the sensory factors used by the crawfish in his endeavors to learn the maze: " In the crawfish, the chief factors in the formation of such habits are the chemical sense (probably both smell and taste), touch, sight and the *muscular sensations resulting from the direction of turning* (italics ours). The animals are able to learn a path when the possibility of following by scent is excluded." (All the experiments cited above from Yerkes and Yerkes and Huggins were made upon normal animals. When they speak of excluding the factor of smell, they mean that they accomplished this by washing the labyrinth thoroughly after each trial.)

Triplett[3] and others who have observed fishes in captivity, have emphasized the keen visual powers of these animals. The

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[1] *Harvard Psychological Studies*, I., p. 579.

[2] ' Habit Formation in the Crawfish Cambarus Affinis,' *Harvard Psychological Studies*, I., p. 565.

[3] 'The Educability of the Perch,' *Amer. Jour. of Psy.*, 1901, Vol. XII., p. 354–360.

experiments of Triplett show that perch, when separated by a glass partition from minnows living in the same tank, slowly learn to cease striking at the minnows. The many experiences which an animal gets by constantly bumping into the partition so fixes the position of it for him, that he will not cross the line of it when the plate itself is removed. We quote the following from Triplett's notes:[1] "On May 4th, glass removed in order to clean tank, but waited to see if fish would cross line. The male swam out to place, stopped, made little bumps forward as if expecting the usual obstruction and was plainly at a loss. He then turned and swam down, as if following the glass." Although Triplett doesn't say so, this behavior strongly suggests a kinæsthetic 'memory.'

Watson[2] found that young rats, 10, 11 and 12 days of age, could return to the mother over a labyrinth path. At the ages mentioned, the rats were blind and deaf. It is suggested in the experiments referred to (see note, p. 85) that the memory of such a pathway is possibly motor. The possibility that smell sensations aided in the return was not excluded. Their behavior, however, did not suggest the use of olfactory sensations.

Miss Allen[3] made some very interesting experiments upon the sensory factors used by the guinea pig in learning a simple labyrinth. She first eliminated the visual factor by forcing the animal to learn the labyrinth in the dark. Comparing the record obtained in this way with a similar one obtained in the light, we find: "(1) The range of variation in reaction time is greater in the dark than in the light; (2) a longer time is required to form a definite habit of entering the cage for food; (3) the average time required, even omitting the excessively long periods, is longer than that required for the analogous experiments in the light . . . ; (4) it follows, therefore, that the number of random movements is much greater in the dark than in the light. This the smoked paper

[1] P. 358.

[2] *Animal Education*, pp. 59 ff.

[3] 'The Associative Processes of the Guinea Pig,' *Jour. Comp. Neurology and Psychology*, Vol. XIV., No. 4, July, 1904, pp. 293–359.

showed to be almost invariably the case." Miss Allen tried to determine the effect of putting colored cards at one of the critical turns. These did not hasten the formation of the association nor, after the association was formed, did their removal disturb the reactions of the animals.

Experiments were also made for the purpose of testing the importance of contact sensations in the ' recollection ' of the labyrinth path: Vision was excluded, and the contact values of the path were altered by substituting a cardboard labyrinth for the original wire one. " A black cloth was spread over the floor of the experimental cage to change still more the tactual conditions." Since under such conditions as are noted above no lengthening of the reaction time is found, Miss Allen concludes " that the path through a labyrinth is not learned solely, or even largely, in terms of tactual sensations."

The positive conclusion reached by Miss Allen from this process of elimination, is that the kinæsthetic sensations are the important sensory factors. Vision and tactual sensations are auxiliaries, but their functions can be dispensed with. Miss Allen's work suffers because of the fact that the number of her animals was so very limited.

Porter[1] makes the following statement upon the basis of his observations of the English sparrow, the vesper sparrow and the cowbird in their efforts to learn a simple maze:[2] " The behavior of the birds in this experiment tends to strengthen the opinion formed from earlier experiments with the more complex maze: namely, that, especially after the maze is learned, the birds do not depend upon sight alone for their cues as to when to turn and in what direction, but on a sense of direction and distance as well. That this is, at least in part, in terms of muscular sensations is probable."

The work of Rouse[3] remains to be cited. The experiments on labyrinth L are discussed by the writer somewhat in detail,

[1] 'The English Sparrow and Other Birds,' *Amer. Jour. of Psy.,* Vol. XVII., No. 2, pp. 248–271.

[2] P. 257.

[3] The Mental Life of the Domestic Pigeon,' *Harvard Psychological Studies,* II., pp. 581–613.

and since they have particular bearing upon our present question, we shall give the author's account of them.[1] In the first place, these mazes were constructed by inserting movable wire partitions in a wooden box. " On entering the labyrinth with the partitions in place the first time, a bird started on its usual course toward the food box; running against the first partition, it made vigorous efforts to push through, flying at the wire and often clinging to it for a short time; some of these random movements eventually brought it to the left of the compartment, and thence, through the opening, into the second compartment, and so on through the others, until finally it reached the food by a series of fortunate accidents. The same general reaction was shown in the case of the next few tests, except that fewer and fewer useless movements were made. . . . The great importance of visual data is brought out by the abrupt lengthening of the periods in the case of tests 23–25 and 26–30, where the light intensities were decreased. The lengthening was roughly proportional to the change of illumination. In the relative darkness, the birds had to reacquire the habits. The same mistakes were made as at first (running against partitions, and into the blind alley), yet here, as before, there was a ready adjustment. That the food was out of sight, or at least very much less visible, probably made no difference, since it was found that the birds would readily go to the old place after both food and food-box had been removed. In order to exclude the light entirely without making their movements invisible to me, I blindfolded the birds by means of a thin black hood, comfortably (?) adjusted over their eyes and top of head; as a result, none was able to make the course in twenty minutes. The first turn, however, was usually made naturally, perhaps because associated with certain non-visual sense-data (sound of the lifting door, and perhaps tactual impressions of the close entrance compartment, etc.)." And just here, at the point where we are becoming interested in his general analysis, he stops it. But let us look a little closely at the data which he uses in drawing the conclusion that visual sensations are of such great importance in the labyrinth.

[1] P. 587.

Why did the birds in the beginning of the learning process flop against the partitions if vision is so all-important? Would they have done so, if the partitions had been of boards and therefore made opaque and more easily visible? Again, if one refers to Rouse's table on page 589 of the article referred to, where the time of the learning process is shown together with the changes in the normal time, produced by the decreasing of the intensity of the light, one finds: 1st, That the effect of the substitution of a 2 C. P. light for the 18 C. P. (the illmination used in the normal learning process) is felt for *only one trial after the substitution is made;* 2d, that the almost entire exclusion of the light ('with a slight illumination through a single curtain, other conditions the same '—is the way Rouse states it) produces marked disturbance upon the pigeons' reactions for only three trials, the fourth trial after the change being practically normal, the fifth trial being quite so. If the pigeon is using *visual discrimination* in the maze to any extent, is it likely that the readjustment made necessary by the great change in the illumination could have been effected in *one trial* in the first case, and in *three to five trials* in the second case? And again, Rouse makes no attempt to separate the tonic and emotional effect of the light from the purely cognitive. May we not suppose that the poor records in these first three trials were due, in part at least, to the presence of fear or excitement and that under the influence of this emotion they reverted for a moment to the instinctive type of behavior? What would have happened if Rouse had forced his birds to live in the dark for a few days, regularly taking their meals there— would they not have learned the labyrinth in the dark? Finally, again referring to his experiments quoted above—did the putting on of the hood show anything? In the first place Rouse fails to state a very essential point in connection with this experiment: for how long were the birds forced to wear this comfortably (?) adjusted hood before they were introduced to the labyrinth? Since no statement is made concerning this, the presumption is that he hooded the pigeons and tested them immediately. If he did this, nobody would expect any one

of them to run the maze in ' twenty minutes.' Finally, ' twenty minutes '—even if the condition of the birds had been made comfortable, is not an exceedingly long time to wait for a blindfolded animal to readjust himself to a situation he knows only ' visually.'

We have cited these results at some length because they are, in so far as the time factor is concerned, so similar to the ones we obtained by removing the vibrissæ of the rats trained to the maze (see page 69). Our conclusion there, however, is that while the sensations from the vibrissæ are doubtless used by the rat in his *immediate adjustments* to the various turns in the maze, still they can easily be dispensed with—and certainly are not used as the basis of the discrimination of the turns nor are they at all necessary to the learning process as a whole. Indeed, it is a little hard for us to see why this same statement of the case does not apply to the pigeon in regard to his use of vision in the maze—at least, Rouse has produced no clear proof to the contrary. He has not proven, in our opinion, that the pigeon makes his turns on the basis of visual discrimination.

In certain other experiments, Rouse proves conclusively that these birds possess acute auditory and tactual organs, and that impressions from these avenues play a large part in the associations of the animal. The apparatus used in reaching these conclusions consisted of two especially constructed labyrinths: one arranged to give the pigeon qualitatively different auditory stimulations at certain turns; the other, to permit similarly of electro-tactual stimulation.

In conclusion, we may say, that while Rouse does not deny that sensations from turning, etc., are utilized by the pigeon, yet he everywhere implies that the adjusting movement is mainly released by the visual impulse. His final conclusion is (page 612): " Visual, acoustical, probably tactual, and certainly organic data are the principal sensory factors of the associations of the pigeons."

Miss Fielde's study of the behavior of the ant[1] *Stenamma fulvum piceum,* in a small but fairly complicated maze, shows

[1] *Proceedings of the Academy of Natural Sciences of Philadelphia,* 1901, pp. 521-544.

that these ants are guided mainly, in their successive trips through the maze by the smell of their own individual trails. Consequently, according to her report there is almost no ' short circuiting ' tendency present in this species of ant.   ' Errors ' are not eliminated.   On being admitted at the pole of the maze opposite to its nest, the ant makes excursive journeys until the nest is found.   If, at repeated trials, the ant is put down at the starting-point, the old trail to the nest is followed with increasing rapidity.   Miss Fielde thinks that ' memory ' also plays a part in the return.   She found that after the animal had traversed its own trail for a number of times, she could remove increasingly larger portions of the trail without causing any disturbance in the animal's reactions.   " This proves," says Miss Fielde, " that the ant does not smell her way at every point, and that familiarity with certain objects under her feet is gradually acquired."

In view of the fact that the literature concerned with the general behavior of the ants and their sensory equipment is so vast and so controversial, and that the order of the ant is so far removed from that of the higher birds and the mammals, we think it wisest not to attempt a further review of the research papers concerning them.   We should like to say in passing, however, that no field in comparative psychology is more interesting nor more fruitful than that of the behavior of the various species of ants, and yet there is no field lying more in confusion.   Nowhere in the literature of this subject does one get a central, psychological point of view.   It is an interesting fact but true, that every man from the layman to the metaphysician on a vacation, has studied the " instincts and habits " of ants—every one, except a well-trained comparative psychologist!   This statement, of course, has no reference to purely biological studies.

(*b*) *Dr. Carr's Experiments with the Maze in Darkness.*

1. *Upon Rats which had Learned the Maze in the Light.* —Dr. Carr trained five rats—three young and two adults— to run the maze perfectly *in the light*.   When the rats had

reached a fairly constant and minimum time for running the maze in the light (this takes about 30 trials by our method, viz., giving the rats 4–6 trials each day), it was decided to test their reactions to the maze in darkness. The record of the last five trials of these rats in the light was used as a basis of comparison with the five trials taken in the evening of the same day.

The method of conducting the experiments with the maze in darkness was as follows: First, they were made at night; second, the heavy shades were pulled down over all the windows; third, a single 16 C. P. electric light was left burning in the room until the rat was put into the entrance enclosure to the maze. The instant the rat took his cue and dashed down the gallery, the light was noiselessly and quickly turned out. A little platform attached to an electric buzzer at the entrance to the food-box signalled the end of the rat's journey.. A continuous stop-watch, muffled by placing it in the pocket, was used in recording the time. For several days during the training process in the light, the rats had been forced to cross the little platform at the entrance to the food-box. The rats soon became accustomed to the drop of the platform and to the ringing of the electric bell. The procedure adopted with reference to the use of the electric light was deemed important in that it would tend to eliminate adaptation to the dark. Of course, we can't say that adaptation to darkness was complete in the case of the rat; but we can say that during his passage through the maze the room was absolutely *pitch dark* to the human observers present. Unless the process of adaptation goes on enormously more rapidly in the retinæ of the rat than in the human retinæ, the maze must have been absolutely dark to the rat. Below, we give the comparison records—the one, the five trials in the light—the other, the five trials given four hours later in the dark.

Judging from these results alone, it would apparently take a microscope to find the influence of vision in the maze association! Four out of the five rats made the trips in the dark in an absolutely shorter time, while the remaining rat (III.)

made the trips in a time approximately equal to the comparison
trials in the light.

MAZE IN LIGHT.

Rats.	I.	II.	III.	IV.	V.
Trials.	Min.	Min.	Min.	Min.	Min.
1	.40	.36	.29	.30	.36
2	.41	.25	.50	.24	.24
3	.46	.33	.25	.24	.24
4	.53	.60	.24	.30	.28
5	.70	.40	.25	.66	.70

MAZE IN DARK.

	I.	II.	III.	IV.	V.
1	.50	.40	.31	.31	.25
2	.33	.25	.50	.26	.30
3	.41	.25	.25	.24	.33
4	.56	.35	.24	.25	.24
5	.41	.45	.24	.29	.30

AVERAGES FOR THE FIVE TRIALS IN THE LIGHT AND THE FIVE IN DARKNESS—EACH RAT SEPARATELY.

In light.	.500	.388	.306	.348	.364
In dark.	.442	.340	.308	.270	.302

2. *Upon Rats which were Forced to Learn the Maze in
Darkness.*—There are two obvious criticisms to be made upon
the results of the above experiments. In the first place, adapta-
tion to darkness might have occurred; second, it may be ob-
jected that the rats had been so thoroughly trained to the maze
in the light that they could do it 'hands down' and with
'their eyes shut'! *i. e.*, automatically. In other words, it
may be said truly that the experiment does not prove that the
rat *does not use* vision even largely in the early stages of the
learning process. The first objection can be met only by ex-
tirpation of the retinæ. The second possible objection was
partially met by Dr. Carr in the following way: The animals
were forced to *learn the maze in the dark* from the very be-
ginning. If vision is necessary or important or used to any
appreciable extent, the fact ought to show itself in the *in-
creased time of the learning process.* The following table
and the accompanying graph (Table IV., Curve IV.) show
the record made by Dr. Carr's rats in learning the maze in
the dark. It is based upon three young rats and is to be com-

pared directly with Table II., and Curve II., the corresponding records for three young rats in the maze in the light.

No. of Trial.	Average. Minutes.	No. of Trial.	Average. Minutes.
	(TABLE II.[1] Showing Dr. Carr's experiments on the learning of the maze by three very young rats.)		TABLE IV. Showing Dr. Carr's experiments upon three rats forced to learn the maze in the dark.
I	9.76	I	31.94
2	22.50	2	27.05
3	3.70	3	3.45
4	3.46	4	1.57
5	2.08	5	5.34
6	1.58	6	.83
7	1.30	7	.88
8	.99	8	.63
9	1.15	9	.75
10	1.05	10	.49
11	1.02	11	.50
12	1.55	12	.52
13	.41	13	.63
14	.51	14	.44
15	.44	15	.40
16	.53	16	.44
17	.33	17	.40
18	.45	18	.37
19	.48	19	.34
20	.48	20	.30
21	.49	21	.29
22	.26	22	.30
23	.33	23	.30
24	.30	24	.34
25	.33	25	.27
26	.35		
27	.50		
28	.30		

The main differences to be found in the two sets of records are as follows: The first two records in the dark are higher than the corresponding ones in the light—and why? Simply because we made a slip in our technique. The rats were fed in the food-box for a few days in the usual preliminay way, but in the light; unfortunately, they were not fed *at the time* they were later to be experimented upon, viz., at 8 P. M. As a consequence, when Dr. Carr took the first two records (both the first evening) the rats were not eager and actually curled up and went to sleep in the maze! This time, again unfortunately, was not taken out. The second noteworthy point about the record in the dark is the fact that it is very much superior, if we neglect the first and second trials, to its mate in the light.

[1] For convenience of comparison Table II. is here repeated. See p. 21.
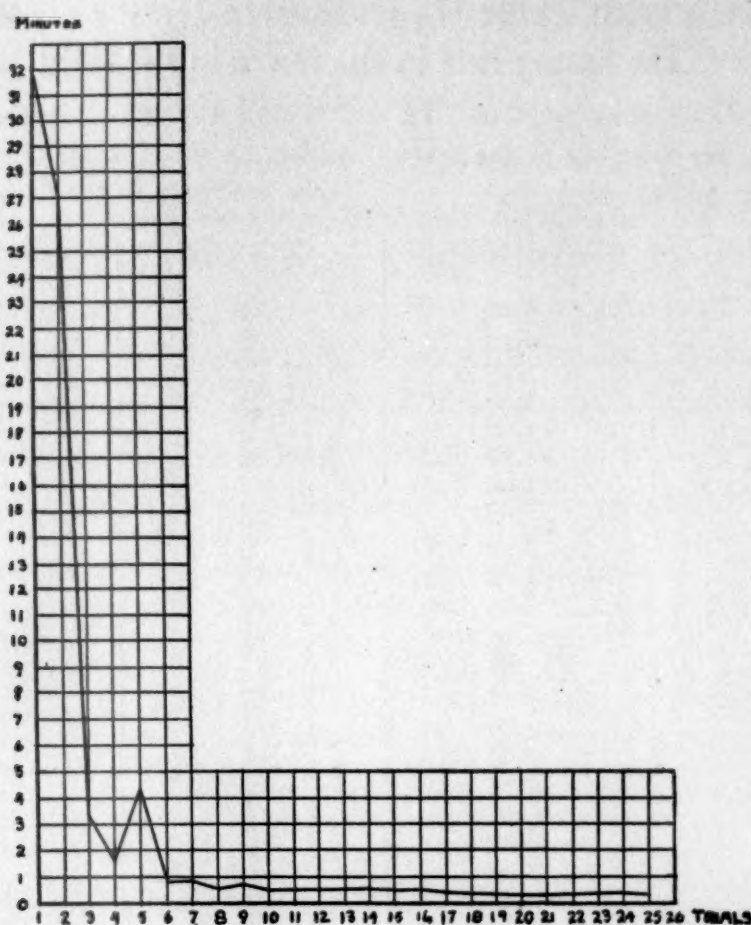
CURVE IV. Showing the record of three rats forced to learn the maze in the dark.

(c) *Dr. Carr's Experiments Designed to Obtain Positive Evidence of the Rôle of the Kinæsthetic Sensations.*

Since the above experiments all tended to support Small's contention, viz., that the tactual-kinæsthetic sensations play the leading rôle in the formation of the maze association, we determined to see what the effect would be if the conditions obtaining in the maze were changed in such a manner that the possible tactual-kinæsthetic impressions would be made more intense. Accordingly, we cut small blocks of wood which would just fit across the galleries; holes, one inch from the bottom edge, were bored in the blocks barely large enough to admit the body of the rat. These blocks were placed in the entrance to the true pathway at every point where the maze offers a choice of turns. *A priori*, it might be thought that the squeezing movements necessary to force the animal through the blocks would bring the kinæsthetic factors into such relief

that the time of the learning process might be considerably decreased. The appended table and its graphical representation show that if anything the learning process is made slightly more difficult. It is certainly ambiguous. A variety of causes may lie at the bottom of this condition of affairs. In the first place, the animal is actually delayed, much like a hurdler, by having to squeeze through these blocks; in the second place, the squeezing process may be highly unpleasantly toned; and finally, owing to our failure thoroughly to accustom the animal to getting through these blocks before beginning the experiment, the emotion of fear was aroused.

TABLE V. Showing the learning of the maze when blocks are inserted at all correct turns where a choice of turns is offered.

No. of Trials.	Average. Minutes.	No. of Trial.	Average. Minutes.
1	23.25	12	.58
2	2.64	13	.51
3	4.60	14	.45
4	14.62	15	.47
5	6.62	16	.83
6	2.37	17	.46
7	1.50	18	.48
8	1.37	19	.59
9	1.16	20	.61
10	1.09	21	.42
11	1.37	22	.48
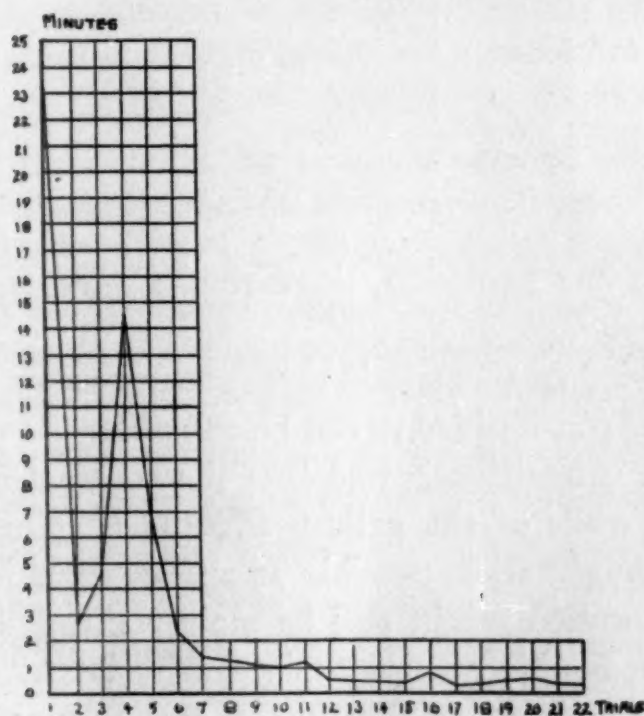
CURVE V. Constructed from Table V.

(d) *Partial Repetition of Dr. Carr's Experiments by the Present Investigator.*

After we had trained the four rats whose records (normal control series) are shown on page 19, we decided to repeat Dr. Carr's experiments with the maze in darkness. Below, we append side by side the control record in the light, and the comparison record made 4 hours later in the dark.

	In Light.		In Darkness.	
	Trial.	Min.	Trial.	Min.
Rat I.	1	.28	1	.30
	2	.38	2	.31
	3	.36	3	.48
	4	.38	4	.27
Rat II.	1	.25	Total failure. He was tried five times—and was allowed five minutes at each trial. He was hopelessly lost in the dark. Each time the light was turned up he was found wandering aimlessly about in the cul-de-sacs. The moment the light was turned up he would find the true pathway and dash to the food. On the following night he was again tried three times, five minutes for each trial, but failed utterly each time. He never failed in the light.	
	2	.25		
	3	.25		
	4	.56		
Rat III.	1	.25	1	.25
	2	.23	2	.20
	3	.25	3	.18
	4	.21	4	.20
Rat IV.	1	.30	1	.20
	2	.23	2	.17
	3	.23	3	.20
	4	.26	4	.17

With the one exception, these results agree with those of Dr. Carr.

Rat II. being an anomaly in these experiments with the maze in darkness, it was decided to test him further.

Professor Angell suggested that the contrast in brightness between the walls of the gallery and the opening made in it at the turns might serve possibly as an ' eye muscle pull,' *i. e.*, that the orientation might still be mainly through kinæsthetic impulses, but, in this rat, they might arise largely by the eye-muscle strain rather than by the general turning movements

of the body and limbs. This suggestion, of course, would be far from denying that the visual impulse plays a part. If it were true, however, it would do away with the necessity of assuming that the rat makes his turns on the basis of visual *discrimination*.

The apparatus for testing this theory was arranged as follows: At all turns in the maze, small miniature lamps were installed (voltage 3½, amperage .19, C. P. in full illumination approximately 3) at the eight critical turns, in such a way that the light would shine from behind directly out through the proper opening into which the animal should turn. These lights (arranged in multiple arc) were connected with a portable sliding rheostat, which in turn was connected with the ordinary 112 volts direct lighting circuit. By means of the rheostat, the little lamps could be changed in intensity from 0–3 C. P. If the above assumption were correct, the faintest glow in the wires of the miniature bulbs ought to be sufficient to produce the necessary eye-muscle pull. After the apparatus had been arranged, the rat was run through the maze for several days until the miniature lamps and their insulated wires ceased to be a matter of interest to him. We shall quote the results of these experiments from our diary.

2/24/06. (1) Rat II. was again tried in the dark for three minutes. He made very many errors by running into practically all the cul-de-sacs. (Permit us to say, that after one has worked with a single maze for two of three years, one can close one's eyes, if the room is quiet, and by the sound that the rat makes in his passage can tell the exact position of the rat in the maze. The writer trained himself to do this, having this very end in view.) At the end of this time, having made no material progress, he was removed from the maze.

(2) The miniature lights were then turned on so as to show only a faint glow. The rat was next admitted. He was materially aided from the start. He would pass the true entrance for a little way, stop and then *invariably* turn into it. Unfortunately, we lost the absolute time of this trial. It was not longer than .75 min.

(3) Time: .50 min. Hesitancy as before but no errors.

(4) Time: .30 min. Clearly and definitely done.

(5) The rat was then tried in absolute darkness. After 2.18 min. of fruitless wandering, he was taken out.

(6) With miniature lights again. Time: .30 min.

2/25/06. (1) The rat was first tried in the dark for 1.55 min. He made a total failure of it.

(2) With miniature lights. Time: .20 min.

(3) With miniature lights. Time: .21 min.

(4) With miniature lights. Time: .23 min.

(5) In the dark again. No success at the end of 2.06 min.

(6) With miniature lights. Time: .30 min.

2/26/06. We were definitely interested by this time to see if the beast could even *learn* to manipulate himself in the dark. We tried him for 33 min. He was eager and worked hard but at the end of that time he gave it up. The room lights were then turned up. He took his cue like a flash. Time: .33 min.

2/27/06. Rat very hungry. Repeated experiment in the dark. No success at end of 24 min. He was then tried with room light turned on.

(1) Time: .33 min.

(2) Time: .33 min.

He was tried in dark again. He was eager for a time but gave up after 12 min.

2/28/06. We began tonight determined to make the rat get to the food in the dark if it took all night.

(1) Success! Time: 10.22 min.

(2) In dark. Time: .65 min.

(3) In dark. Time: 6.85 min. Tried to gnaw into food-box.

3/1/06. Five trials given with the maze in darkness.

(1) Success. Time: .26 min.

(2) Success. Time: .23 min.

(3) Success. Time: .38 min.

(4) Success. Time: .20 min.

(5) Success. Time: .28 min.

3/2/06. Conditions the same.

(1) He got hopelessly lost in the dark. Returned to starting point again and again. Both active and hungry. Time: 12 min.

(2) Ceaseless wanderings as in first trial. Time: 5.35 min.

(3) Time: .66 min. Some few errors were made.

(4) Time: .96 min. Some few errors were made.

3/3/06. Conditions the same. Four trials in the dark.

(1) Time: .20 min. Splendid work.

(2) Time: .23 min. Splendid work.

(3) Time: .25 min. Splendid work.

(4) Time: .23 min. Splendid work.

3/11/06. Unavoidably, several days elapsed without trial. In dark.

(1) Time: .31 min.

(2) Time: .28 min.

(3) Time: .41 min.

(4) Time: 10.00 min. Hopelessly lost again.

3/12/06. Conditions the same. Four trials in the dark.

(1) Time: .25 min. Very consistent work.

(2) Time: .20 min. Very consistent work.

          (3) Time: .41 min. Very consistent work.
          (4) Time: .43 min. Very consistent work.
3/13/06.   Conditions the same. Four trials in the dark.
          (1) Time: .20 min.
          (2) Time:: .20 min.
          (3) Time: 11:00 min. Lost.
          (4) Time: 7.48 min. Lost.
          (5) *In light.* Time: .26 min.
3/15/06.   Conditions the same. Four trials in the dark.
          (1) Time: .20 min.
          (2) Time: .50 min.
          (3) Time: .50 min.
          (4) Time: 1.03 min.

We despaired at this point of ever getting the rat to reduce his time to a low and constant one. He has definitely improved but he is not consistent even after a number of trials.

The following summarized statements may be made concerning the behavior of this rat: (1) His behavior in the maze in the dark is in marked contrast to that of the eight other rats tested under identical conditions. (2) The assumption that the sensations arising from the changes in the brightness intensity at the critical turns *associated with certain strain sensations* arising in the eye-muscles serve as the releaser of the motor impulse, is the simplest one which will fit the facts—it being far more logical, in view of the above experiments, than the assumption that orientation is made on the basis of visual discrimination alone. (3) There is a final possibility; this rat was not quite so strong and hardy as the other rats. The effect of the light might have been general and stimulatory rather than specifically visual, *i. e.,* visual in the ordinary cognitive sense of the term.

From the above historical survey of the field, and from the report of these, hitherto, unpublished experiments made in this laboratory, it becomes evident, that if our analysis of the sensory factors necessary or contributory to the formation of the maze association is to be complete or convincing, we must make the analysis from data obtained from the behavior of rats whose visual, olfactory and auditory organs have been extirpated, for only in this way can we become even reasonably certain that impulses from a given sensory pathway have

been excluded.   Neither the experiments of Small, nor those made in this laboratory prove conclusively that vision plays no rôle in this association—it stands as a criticism against our own work (and Dr. Carr's) that we have not excluded the possibility of adaptation to darkness; the sense of smell may play the preponderating rôle after all—even Small suggests that the behavior of rats whose olfactory nerves have been paralyzed ought to be observed in order to make his own inferences, obtained from the observation of their normal behavior in the maze, more secure; while it is probably not true, it is at least not utterly fantastic to suppose that auditory sensations (or, more strictly, tactual sensations aroused by the effect of the changing pressure of the columns of air upon the tympanic membrane) may contribute some data; pure tactual sensations may *at least* be contributory—especially those arising in the soles of the feet and in that delicate and ever-moving set of vibrissæ; the rat may have some distance sense—' facial vision,' ' temperature ' or what not—which the human organism possesses only in a comparatively rudimentary form.[1] Finally, while ridiculous from the standpoint of human behavior, it is not wholly ridiculous in the case of the rat, to suppose that gustatory sensations contribute data—at least this might be the case where the animal is denied certain other afferent impulses, and thereby is forced to rely more upon the few sensory avenues which an unkind providence has left him.

Believing that the observation of rats with defective sense organs would aid us in returning a more or less complete answer to these and similar questions, we decided to extirpate the sense organs of vision, olfaction and audition.

In the spring of 1905, while the writer was in Baltimore, he began experimenting upon methods of operation designed to remove the special senses in these animals, or where removal was impracticable, to decrease very greatly the sensitivity of the function of these organs.   The work was done under the direction of Dr. Howell, Director of the Physiological Laboratory of Johns Hopkins University.   The writer wishes here

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[1] From certain experiments upon the rotated maze the possibility arises that static (?) sensations may likewise be contributory.

to express his obligations to Dr. Howell and to the members of his staff, both for their personal direction and for the use of their laboratory. The animals operated upon at Johns Hopkins were not used in the experiments. On our return to the University of Chicago, in October, 1905, the operations immediately to be described were made upon tamer animals than could be obtained in Baltimore.

II. *Operations to Remove the Senses of Vision, Olfaction and Audition.*

(*a*) *Method of Operating when the Eyeball is Removed; the Recovery from this Operation.*

In all of the operations which we are now about to describe, aseptic precautions were taken when possible. It is impracticable, however, in operating upon an animal as small as the rat to use all the refinements adopted in modern surgery. Fortunately with the rat this makes very little difference: He seems to be able to withstand almost any amount of exposure to sepsis and show no ill effects. In none of these experiments was any sign of infection ever noticed. The white rat takes the ether extremely well. In the beginning, before the technique of the more difficult operations was well established, our rats were often under the influence of ether from 1 to 1½ hours.

In view of the fact that the removal of the whole eyeball does away with any possibility of even vague brightness sensations, we chose this method rather than that of enucleating the lens. It was feared before the operation that grave trophic disturbances of the metabolism of the animal as a whole might result from the total removal of the influence of the optic tract, but we thought best to try the method at any rate. *Our animals invariably recovered, nor did they show any signs either of immediate shock effects or of slower and more remote systemic effects.* Three animals operated upon in this way more than five months ago are still in good condition.

In removing the eyeball, the animal was first made completely anæsthetic. The vibrissæ and longer hairs were then

removed. The whole eye-ball, lids, etc., were next thoroughly cleansed. A small, especially constructed hook was inserted into the sclerotic and by means of this the whole eyeball was pulled forward. With fine, sterile scissors, the connective tissue and muscles were cut away. This can be done practically without hemorrhage. The eyeball was then pulled still further forward, thus exposing more completely its attachment to the optic tract. This was next cut away with one stroke of the scissors. A rather profuse hemorrhage, produced by the sectioning of the ophthalmic artery, then occurred which we did not attempt to check. In a short time, this ceased of its own accord; the cavity was next thoroughly cleansed with sterile normal salt solution. The second eyeball was then removed, additional ether being administered by means of a cone if necessary. The animal was then put into a small freshly cleaned cage and allowed to recover. No effort was made to close the site of the wound or to restrain the animal from scratching it. Of course, in this way, we ran the risk of having infection develop. It is almost impossible, however, wholly to prevent the possibility of this in the eye operation.

In order to show the almost total absence of any shock effects resulting from the above described operation, we shall quote the following from our notes:

" Four male rats, all from one litter, born September 10, 1905, were operated upon March 24, 1906. Both eyeballs removed. The immediate shock effects were almost *nil*. The rats accepted food six hours after the operation. Twenty-four hours later they had thoroughly cleansed themselves. Motor control perfect. Several difficult feats were performed during this period of observation, such as balancing upon the rim of their little 8″ by 4″ wire cages. They walked around the edge of these cages with ease. They balanced themselves upon a small stender dish containing water—hind legs on dish, fore legs in air. One rat obtained some food, a second followed, bowled the first rat over, felt in his mouth and removed the food contained there. Two other rats were seen to play!

" 48 hours after operation: The rats were absolutely normal so far as we could judge. Motor control perfect. Appetite

fine. Eager curiosity exhibited when the rats were released. No signs of irritableness. These rats, even at this early stage, do not run with heads any higher or any lower than normal rats. If we could not see that their eyes had been removed, it would be absolutely impossible for us to tell them from the normal rats!

" 72 hours after operation: Wound shows no sign of infection. Appetite splendid. They scramble and fight for food.

" 96 hours after operation: Hale and hearty. All four rats engaged for a long time in a playful rough and tumble fight. Movements characteristic of the combats indulged in by normal rats were made perfectly; one rat falls down while a second stands over him and grasps his throat or mouth.

" 5 days after operation: All four rats were transferred to one large cage. The food and water in it were found without useless movements. The storing instinct was exhibited. One rat was observed to sit near a pile of sunflower seed: at intervals, he would stretch out his neck and help himself. He never made a mal-coördination by over or under innervation nor by moving his head too far, either to the right or to the left."

Enough has been quoted from the diary, we think, to show that the shock effects from this operation are so mild as to be hardly noticeable.

(b) *Method of Operating when the Olfactory Bulbs are Removed; the Recovery from this Operation.*

Since it is impracticable to remove the peripheral olfactory nerves, we decided that the easiest way to exclude the possibility of reactions to olfactory stimuli was to trephine and actually to remove the bulbi olfactorii. This is an exceedingly easy operation due to the fact that the bulbi lie entirely cephalad to the frontal lobes and not ventral to them, as can easily be seen from the appended cut.

The bulbi are well developed and their line of junction with the frontal lobes can easily be seen through the cranial bones, after the skin incision has been made. This junction point

lies on the line connecting the posterior angles of the lids of
the two eyes.   With a very small, well-tempered trephine drill
a series of tiny holes was made in the form of an oval around
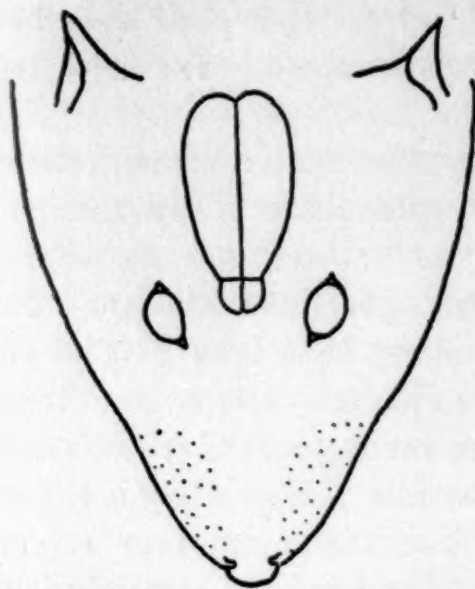
FIG. 2.   Showing the relation of the bulbi olfactorii to the hemispheres and
to the head as a whole.   (Life size.)

the two bulbi.   The little island of bone was then removed.
If care is taken not to injure the frontal sinus in the drilling
process, the bulbi can be exposed entirely without the loss of
a drop of blood.   A small, especially constructed, double-edged
knife was next inserted at the junction of the bulbi with the
frontal lobes.   This knife was forced vertically down to the
supporting floor of the bulbi and then driven from left to right
until a complete separation between the bulbi and the frontal
lobes was effected.   With a very small eye curette, the bulbi
thus severed were rapidly and thoroughly removed.   Nat-
urally, a profuse hemorrhage occurred, due principally to the
sectioning of the frontal sinus.   The actual loss of blood
during the hemorrhage varied greatly from individual to indi-
vidual.   This accounted in part for certain differences in the
behavior of the rats during the period of recovery.   By
gently tamponing the cut ends of the vessel, the hemorrhage was
soon controlled.   The cavity thus made was thoroughly washed
with sterile salt solution and then sponged.   Any material of
the bulbi remaining from the first curetting process was re-
moved.   The operation *in all cases* was made absolutely com-

plete. After the checking of the hemorrhage, and the sponging process following upon this, the whole cavity was blood-free and remained so, thus affording a complete view of the operated field. After the removal of the bulbi had been completed, the skin flaps were stitched together; collodion being applied along the line of incision. The animals were then put into individual, sterile cages, and kept there until recovery was complete.

In this case recovery is slower than in the visual operation. The animals are more irritable and pugnacious than usual and show a disposition to strike their heads against the sides of their cages. The contraction of the collodion which covered the site of the wound may account for this behavior. They seem unusually sensitive to light from which they attempted to protect themselves by stuffing cotton into the meshes of the cage on the side from which the light came. Four weeks after the operation the wound had so completely healed over that had we not marked their ears we should have been absolutely unable to identify them among the normal animals. Needless to say, their behavior gave us no clue whatever.

(c) *The Method of Operating when the Middle Ear is Removed; the Recovery from this Operation.*

Thoroughly to eliminate the influence of air vibrations, one must cut the cochlear branch of the eighth nerve or else destroy the inner ear. Both of these operations are exceedingly difficult to perform with sureness and certainty.

For our purposes, neither was supposed to be necessary. In the first place, it was thought that if the slight noises made by the animal in his passage through the maze aided him in making his turns at the critical places, then the mechanism by means of which this is done must be exceedingly delicate, for, as has been stated, the sounds made by the rats in the maze are very faint; and the differences in the reflection of these sounds (which, if this were the *modus operandi,* would be the only way in which a discrimination could be made) would be fainter still. The conditions under which the normal animals had to learn the maze ought, however, to rule out of court the supposition that air waves (*i. e.,* those producing the con-

ditions for the arousal of an auditory sensation as such) influence the reactions of the rat to the maze. Briefly, the conditions are these: The one large room where these experiments were all made, is surrounded on the one side immediately by a large ventilating fan and its motor, on the other, by a machine shop—a peculiarly active place, containing a motor, an emory wheel and an instrument for grinding, boring and polishing glass. In addition to these rather constant noises, there were others coming from a large number of rats kept in the same room with the maze. To any one familiar with ' rat noises,' no further description of the immediate surroundings of the maze need be given.[1] After this description of the noises in which the rats had to learn the maze, we venture to say that no one would have the hardihood to suggest that the sensations of sound produced by the rat himself could influence his behavior in the maze.

The aid from the aural organ, if any aid is contributed by it, would presumably more probably arise from the effect of the changing pressure of the columns of air upon the tympanic membrane. Doubtless these columns of air do change as one passes from a long gallery into a short one, as one approaches an opening into a gallery, or finally, as one approaches the end of a cul-de-sac. The important question is, has the rat any sensory mechanism in the ear drum, or in the skin of the nose, wherewith to sense these changes in the density of the air?

By the destruction of the drum membrane, the removal of the chain of bones and the filling of the middle ear cavity with paraffine, the aural mechanism which would be likely to become functional under the influence of the changes in air pressure is placed *hors de combat*. In addition to this advantage, the above operation for a time, at least, leaves the rat almost absolutely deaf.

This operation can be made quickly without the loss of one drop of blood. The animal is anæsthetized, placed on one side, and a small skin incision is made running vertically down from the ventral limit of the concha of the ear. This exposes

[1] *Cf.* Porter's difficulties at Clark University! *Am. Jr. Psy.,* Vol. XVII., No. 2, p. 248.

more thoroughly the cartilaginous tissue of the meatus. An incision is made horizontally through this tissue of the meatus. Small artery clamps are attached to the concha and to the meatus in such a way that the tissues of both are pulled away, exposing the drum membrane and the handle of the hammer bone. Two tiny forceps are next employed, one to serve as a speculum, the other to destroy the drum membrane and to break up the system of bones. No effort was made actually to remove the bones; sometimes one can do this, but more often one loses them in the middle ear cavity. An especially constructed long needle-pointed medicine dropper was then used to inject the paraffine. The paraffine had been previously filtered and sterilized. By melting hard and soft paraffine together, a final melting point of 40° C. was obtained. The entire cavity of the middle ear is then filled with paraffine. The skin and cartilaginous incisions are next sewed up and the site of the wound covered with collodion.

The recovery of the animals from the above operation is rapid. We cite the following statements from our notes:

" 8/9/06. Middle ear of two females removed. Recovery from anæsthetic rapid.

" 1 hour after operation. No motor disturbances of any kind apparent. No reactions to sound could be obtained; the prolonged and shrill noise mentioned above, which gave 'the shivers' to the normal rats, produced not the *slightest sign of movement in these rats.* Noises deep and high produced by striking the various objects in the room were without effect.

" 24 hours after operation. The shock effects have practically disappeared. The animals show hunger and the usual amount of food is consumed. Extensive tests were made today with the Edelmann whistle. Normal rats are very sensitive to the sounds produced by this instrument. We have been able to obtain reactions with it throughout all the ranges of its pitch up to 17,000 vibrations per second. With these defective rats, we could obtain no sign of response to any of its tones.

" 6 days after operation. The rats are in fine condition. They were fed today in the food-box of the maze for the first

time since the operation (they had been fed there for seven days previous to the operation). Some slight signs of the return of the auditory function were observable today. The tests were made with an ordinary call-bell (this bell gives a loud, clear, distinct note whose pitch is 1200 S. V.). The normal rats react to this bell by a violent, backward movement of the whole body. An instant of inhibition follows which keeps the animal 'stock still.' The defective rats, when they noticed it at all, reacted to it with a barely perceptible shake of the head—their other movements (examination of surroundings, etc.) were in no case disturbed by the stimulus."

In all these tests upon the extent to which these rats are sensitive to sound, care was taken to have more than one observer present. All agreed that the rats' sensitivity to sound was enormously decreased by the operation. We ourselves were satisfied that the operation was perfectly complete for all the purposes concerned in the present investigation.

III.   The Behavior of Defective Rats in the Maze.

(a) *The Behavior of Rats Trained to the Maze with Sense Organs Intact, After the Loss of Vision.*

Our first test upon the behavior of blind rats in the maze was made upon three animals which had *learned the maze with sense organs intact.* The original record of the learning of the maze by these rats has already been shown in the ' normal control series.' Four rats were used to obtain this series, but it will be remembered that rat II. was an anomaly as regards his tests in the dark. We decided not to operate upon him, but to keep him as a control animal, if such should be needed. Before describing these further experiments upon the blinded rats, let us recapitulate their experiences in the maze. In their normal condition, they had been given 50 trials in the light. We then tested them to see how well they could run the maze in the dark. It was found that rats I., III. and IV. could run the maze as well in the dark as in the light. In our discussion of these results, we decided that adaptation to darkness might possibly have aided the rats in their journey through the maze.

The only way absolutely to exclude this factor was to remove the retinae of these animals. Accordingly, they were operated upon in the above described manner. Their recovery was rapid and complete. The rats were not again tested in the maze until 25 days after the operation.[1] The 37 trials given the blind animals are shown in Table VI.; Curve VI shows the first ten of these trials in graphic form. This table and curve are to be compared with Table I. and Curve I.

TABLE VI. Showing the effect of the loss of vision upon three male rats trained to the maze with sense organs intact. The *average, minimum* and *maximum* times are given.

No. of Trial.	Average. Minutes.	Minimum. Minutes.	Maximum. Minutes.
1	2.39	1.83	3.00
2	.95	.76	1.13
3	.85	.66	1.01
4	.65	.41	1.06
5	.66	.50	.96
6	.51	.35	.71
7	.42	.20	.58
8	.34	.25	.41
9	.33	.30	.38
10	.30	.26	.36
11	.52	.33	.71
12	.52	.33	.73
13	.39	.25	.46
14	.29	.25	.33
15	.38	.30	.45
16	.38	.25	.58
17	.31	.20	.45
18	.46	.26	.71
19	.28	.28	.30
20	.27	.23	.31
21	.25	.20	.30
22	.28	.20	.38
23	.36	.20	.50
24	.25	.20	.31
25	.31	.25	.41
26	.38	.23	.53
27	.23	.20	.26
28	.25	.21	.30
29	.25	.23	.28
30	.27	.23	.30
31	.27	.25	.30
32	.23	.21	.26
33	.27	.23	.33
34	.24	.21	.26
35	.24	.20	.28
36	.25	.25	.25
37	.27	.26	.30

[1] In all cases ample time was given for complete recovery before the animals were tested in the maze.

An examination of these records will show that the average of the first trials of the three rats is the only one requiring over one minute.　If one compares these records of the blind rats in the maze with their original records in *learning* the maze,

CURVE VI.　Based upon Table VI.

one cannot avoid the conviction that the rats' ability to run the maze after he has once learned it is little affected by the loss of vision, if it is affected at all thereby.　The record of the blind rats would have been better undoubtedly if we had properly controlled the conditions for their first few trials in the maze subsequent to the operation.　In the first place, the rats were given all they could eat during the 25 days allowed for convalescence.　Consequently they were exceedingly fat when we tried them in the maze for the first time.　We should have starved them, or rather, have fed them lightly in the food-box of the maze for at least *one week* before allowing them to traverse the maze.　In the second place, the blind rats were badly frightened by the noise and movement of the trap (used in experiments with the maze in darkness) which we had allowed to remain in the maze, for fear its removal would change the olfactory conditions.　The rats would come up to the plane and touch it, but the moment they felt it move they turned back—finally mustering courage, they ran over it, but the jolt they received from it coupled with the noise made them extremely cautious when again nearing it.

We finally decided to remove the trap.　In its place, we inserted a new, smooth floor in the gallery.　We accustomed the rats to this new condition of things by shutting them up from the rest of the maze and forcing them to run over the new floor for several trips.　An interesting bit of behavior came to light.　The rats went on jumping over the *now perfectly even floor* just as they would have done if the trap had been present.　They repeated this many times even after we

had started them regularly to traversing the maze. In order that the above statements concerning the behavior of these rats may be illustrated, we quote the following individual records from our diary:

" Trained rats in the maze after destruction of vision.

" Rat I., 1st trial. (Rat I. in originally learning the maze was very timid. This was evidenced by his creeping round corners and hugging the sides of the galleries (see maximum time for 1st trial in the normal control series, page 19). In this first test after the loss of vision, he reverts to his original type of behavior.) He evidently was not very hungry. *He ran the first half of the maze absolutely without error. He then turned and retraced his way to the entrance, again without error. He turned at the entrance, got his cue and went to the food-box without error.* Total time: 2.35 min.

" Rat IV., 1st trial. Walked very slowly. Made several errors in *A*, *B* and *D*, apparently out of ' curiosity.' ' Back tracks.' Time: 3.00 min.

" 2d trial. Walked slowly but *did not make an error.* Time: .76 min.

" 3d trial. Hesitancy (but no error) at one turn. Time: .66 min."

Our records show that all the trials subsequent to the first were without error.

Again our work loses part of its definiteness by our not knowing just what percentage of the loss in the rapidity of these first few trials after the operation is due to the process of ' forgetting.' (We thought we had provided for a control record by setting aside Rat. II., the ' anomaly ' in the test on ' maze in darkness.' But it took us nearly 25 days to finish our experiments upon him, *i. e.,* to see whether he could learn to run the maze in the dark. Consequently, when the time came to test the blinded rats, rat II. was in perfect training.)

But even if these records were taken at their face value, we feel sure that our first point is made, viz., that when *once the normal rat learns the maze, the definiteness of his reactions to it* is little affected by the loss of vision. These results

from the experiments on the defective rats confirm those obtained by Dr. Carr and ourselves upon the normal trained rats with the maze in darkness. They add to those results, in that *here* any possible adaptation to darkness is impossible.

(*b*) *The Behavior of Blind Rats in Learning the Maze.*

There is still the possibility existing, that the rat may use vision in the *learning process*. While Dr. Carr, whose results have already been given, has gone a long way toward proving that such is *not* the case, by showing that normal rats can *learn* the maze as readily in the dark as in the light, there is a chance that adaptation to darkness (during the long early trials) might have entered in to aid the rats in making the records referred to. To prove that adaptation to darkness had no hand in the process of learning the maze in the dark, we removed the eyeballs from four *untrained* rats. The record of the recovery of these four rats together with their ' biography ' has already been given upon page 48 of this paper. These four rats were not introduced to the maze until 42 days after the removal of their eyeballs. In Table VII. and its graphical representation, Curve VII, we show the phenomenal record made by these rats in learning the maze.

There is nothing to be gained by discussing these results in detail—the descriptions of the behavior of the normal rats in the maze already given by Small and ourselves sufficiently describe the method used by the blind rats in learning it. So far as we could judge, their behavior was absolutely normal. It is interesting to add, however, that the blind rat in learning the maze does not ' butt ' into the cross pieces in the cul-de-sacs. He runs squarely down the middle of the galleries. He makes his turns into the various entrances as boldly and with as much sureness as do the nomal rats. The vibrissæ undoubtedly play a large part (though not an indispensable one) in the early reactions of these rats to the maze. But since the function of their vibrissæ is separately treated later on, we shall not dwell upon it here.

These experiments upon the untrained, blinded rats lend the needed control factor to Dr. Carr's experiments upon the

TABLE VII. Showing the average, minimum and maximum times of four blind rats in *learning* the maze.

No. of Trial.	Average. Minutes.	Minimum. Minutes.	Maximum. Minutes.
I	6.20	2.50	11.25
2	5.00	1.40	15.18
3	1.77	.93	3.53
4	1.78	.81	2.50
5	1.97	1.36	2.88
6	.73	.35	1.20
7	1.94	.71	4.93
8	1.89	.30	4.26
9	.52	.41	.63
10	.71	.25	1.38
11	.34	.25	.50
12	.57	.30	.73
13	.56	.25	1.00
14	.28	.23	.35
15	.24	.20	.26
16	.46	.25	.75
17	.24	.16	.30
18	.37	.18	.71
19	.32	.28	.41
20	.74	.30	1.85
21	.41	.25	.75
22	.26	.21	.35
23	.27	.25	.41
24	.36	.23	.53
25	.27	23	.31
26	.30	.23	.50
27	.27	.20	.41
28	.22	.16	.30
29	.23	.18	.33
30	.23	.18	.30
31	.19	15	.23
32	.22	20	.25
33	.24	18	.33
34	.25	20	.30
35	.22	.18	.26
36	.31	.16	.65
37	.20	.16	.25
38	.18	.18	.20
39	.19	.16	.23
40	.19	.18	.25
41	.21	.18	.26
42	.20	.16	.26
43	.18	.18	.20
44	.19	.16	.21
45	.21	.18	.25
46	.20	18	.23
47	.21	.18	.30
48	.19	.18	.21
49	.20	.20	.20
50	.18	.16	.18

normal rats in learning the maze in the dark. They show, in our opinion, that his normal rats in thus learning the maze in the dark were not aided by any possible supra-human power of adaptation to darkness.
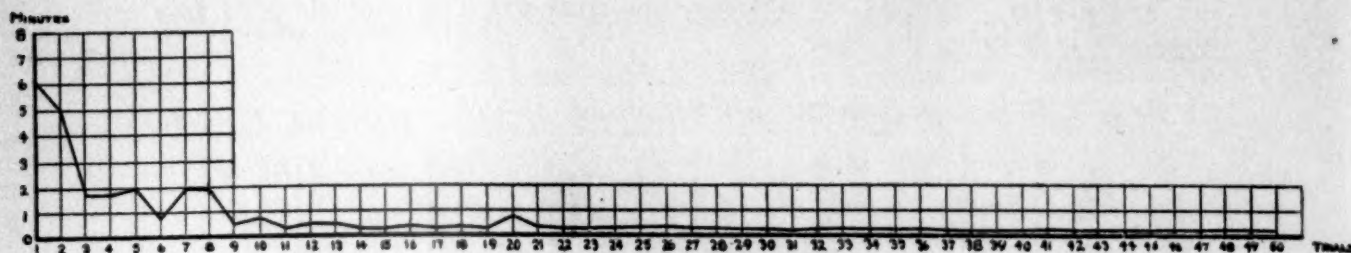
CURVE VII.   Constructed from Table VII.

(c) *The Behavior of Anosmic Rats in Learning the Maze.*

After having excluded vision, in our own opinion at least, as a necessary factor or even as an important auxiliary factor in the formation of the maze association, five rats, whose olfactory bulbs had been removed in the above described manner, were tried in the maze. Of these five rats, three were males and two were females. Two of the male rats were brothers of the four blind rats whose records we have just finished. The third male was a young rat, 150 days old. The two females were a little older but their exact ages were unknown. All five of the rats were in fine condition at the time of this experiment, but the two females were undoubtedly the finest rat specimens it has ever been our pleasure to examine. They were always active and curious whether hungry or well-fed.

Forty days were allowed to intervene between the operation and the first trial in the maze. All five rats were fed in the food-box of the maze for several days in the usual preliminary way before they were allowed to learn the maze. None of the rats had ever learned any problem prior to their experience with the maze. The records of these anosmic rats are shown in the following tables and curves (Tables VIII., IX. and X. and their corresponding curves). Table VIII. and its graphical representation, Curve VIII., show the averages of all five rats at each of the fifty trials. Table IX. and Curve IX. show separately the similar averages of the three male rats. Table X. and Curve X. show the corresponding separate averages for the two females.

TABLE VIII. Showing the average, minimum and maximum times of five anosmic rats in *learning* the maze.

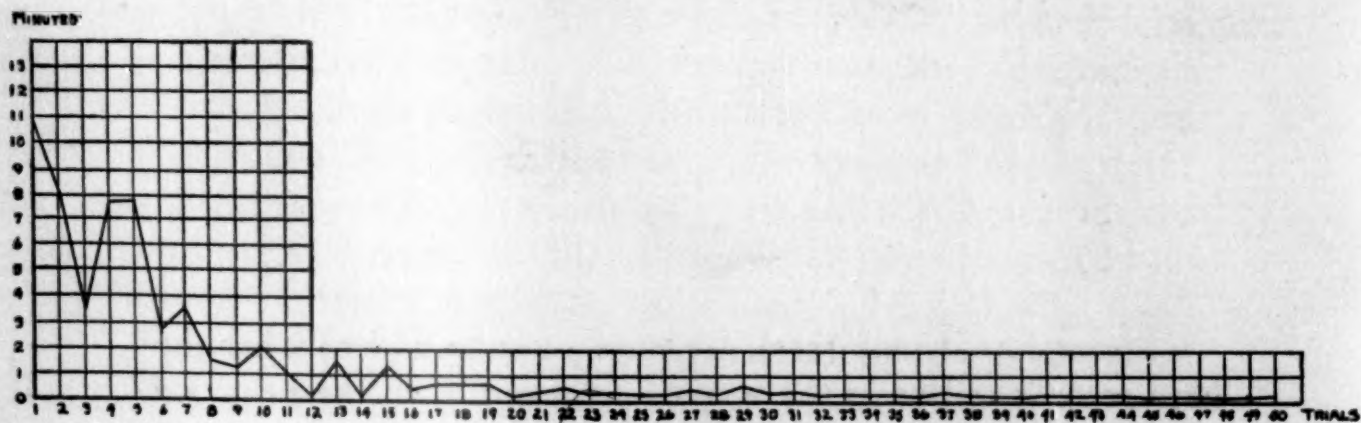| No. of Trial.	Average. Minutes.	Minimum. Minutes.	Maximum. Minutes.
1	8.17	1.73	20.36
2	5.61	1.35	13.91
3	5.25	1.50	14.00
4	6.02	1.01	8.76
5	5.45	1.10	19.00
6	2.45	1.01	4.00
7	2.82	1.08	5.90
8	1.68	.88	2.75
9	1.35	.35	2.30
10	1.62	.35	5.20
11	1.03	.33	1.66
12	.71	.25	1.30
13	1.08	.20	2.66
14	.63	.25	1.08
15	1.14	.68	1.83
16	.43	.25	.63
17	.68	.58	.83
18	.51	.16	1.41
19	.56	.23	1.11
20	.34	.38	.55
21	.37	.20	.83
22	.48	.25	1.03
23	.37	.25	.43
24	.33	.16	.61
25	.33	.23	.50
26	.30	.15	.58
27	.44	.23	1.15
28	.26	.20	.41
29	.45	.20	1.31
30	.28	.18	.43
31	.29	.16	.58
32	.24	.16	.41
33	.30	.21	.50
34	.32	.20	.50
35	.28	.16	.63
36	.23	.15	.28
37	.33	.18	.71
38	.21	.15	.30
39	.22	.16	.28
40	.27	.20	.30
41	.25	.18	.33
42	.23	.18	.33
43	.21	.16	.26
44	.24	.18	.40
45	.23	.20	.30
46	.24	.18	.30
47	.21	.18	.23
48	.20	.16	.25
49	.21	.16	.26
50	.21	.16	.26

Strange as it may seem, we have little to add to what the bare records tell us in the way of comment upon the behavior of these anosmic rats in the maze. In short, their behavior
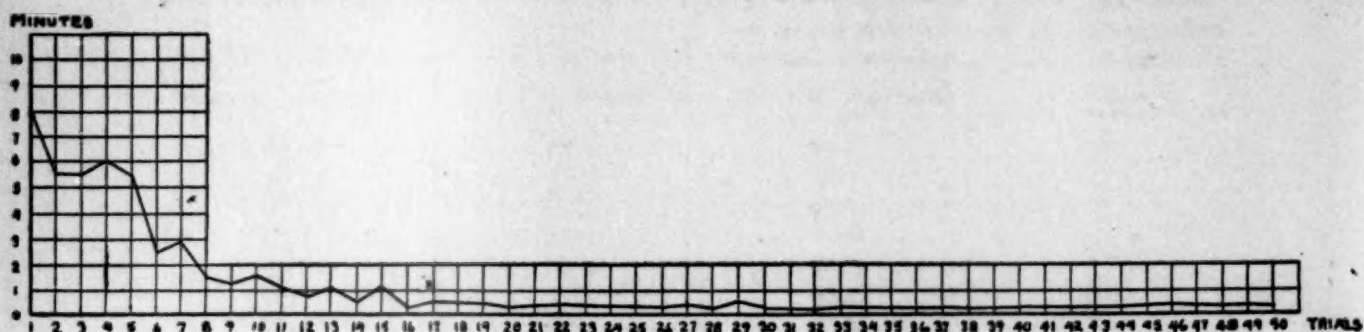
CURVE VIII.   Constructed from Table VIII.

TABLE IX.   Showing the averages of three anosmic males for learning the maze.

| No. of Trial.	Average. Minutes	No. of Trial.	Average. Minutes.
1	10.88	26	.39
2	8.19	27	.57
3	3.58	28	.30
4	7.73	29	.62
5	7.86	30	.35
6	2.74	31	.39
7	3.68	32	.28
8	1.59	33	.36
9	1.48	34	.35
10	2.17	35	.35
11	1.05	36	.28
12	.17	37	.44
13	1.59	38	.23
14	.18	39	.25
15	1.38	40	.25
16	.53	41	.29
17	.72	42	.27
18	.73	43	.25
19	.78	44	.28
20	.44	45	.25
21	.46	46	.24
22	.62	47	.23
23	.39	48	.22
24	.43	49	.25
25	.36	50	.25

CURVE IX.   Constructed from Table IX.

TABLE X. Showing the averages of two anosmic females for learning the maze.

No. of Trial.	Average. Minutes.	No. of Trial.	Average. Minutes.
1	4.10	26	.16
2	1.74	27	.24
3	7.75	28	.21
4	3.45	29	.20
5	3.82	30	.22
6	2.03	31	.16
7	1.53	32	.18
8	1.82	33	.23
9	.66	34	.28
10	.80	35	.18
11	.99	36	.15
12	.31	37	.22
13	.30	38	.18
14	.27	39	.18
15	.78	40	.29
16	.27	41	.19
17	.62	42	.19
18	.18	43	.16
19	.24	44	.19
20	.20	45	.20
21	.24	46	.24
22	.27	47	.19
23	.34	48	.18
24	.20	49	.17
25	.29	50	.16
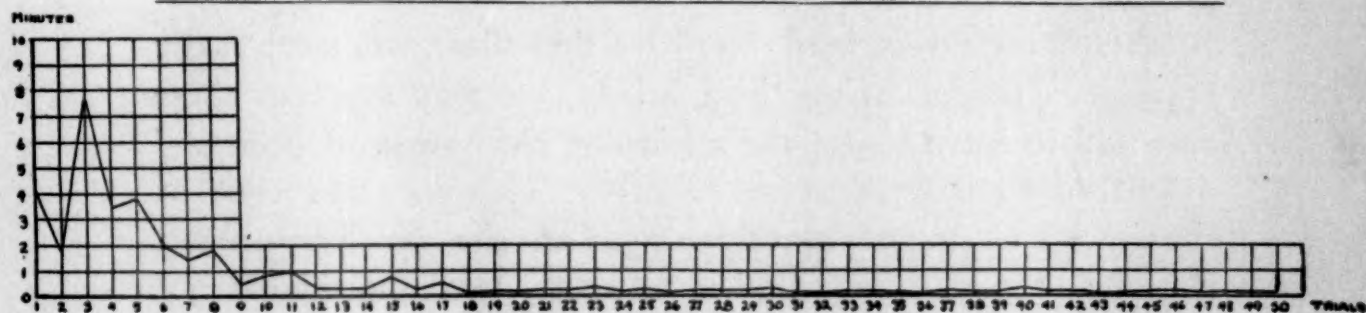
CURVE X. Constructed from Table X.

in regard to the making of errors, the elimination of errors, etc., may be characterized as being normal. At first, we thought that the anosmic rats were going to take longer to get their ' cue ' than the normal rats, but we found this to be true only for the first three or four trials. This failure to get the cue to the beginning of the series of movements the moment the anosmic rat is put down in the entrance is probably due to the lack of the customary olfactory sensations set up by the food which must act in the normal rats, at least in conjunction with the complex group of organic sensations (the hunger complex). When a normal rat is put down into the

entrance to the maze, as has already been mentioned, he usually loiters for an instant, then darts down the gallery. The inference is that the loitering is due to the swamping of the olfactory and organic neural impulses (which would ordinarily discharge into the motor area in the cortex, and thus condition the initial movement in the series) by the complex group of neural impulses (producing an ' emotion,' to phrase it in conscious terms) coming from the tactual, kinæsthetic and auditory stimulations incident upon the animal's introduction to the maze. The moment these subside, the neural impulses set up by the whiff of the food, coupled with those underlying the ' resurgence of the feeling of hunger ' (Small) can discharge normally into the motor center. So far as we can see, there is no difficulty in this respect offered by the anosmic rats. All we need assume is that here the organic complex alone can discharge into the proper motor center and by so doing release the movement which formerly had been released by both sets of afferent impulses.

Many tests were made to prove that these rats were really anosmic. Summarizing them briefly, we may say that these rats had to learn to get their food by the ' sense of position ' (sight does not seem to aid them). This was true even of cheese, which might conceivably affect the N. Trigeminus. But the ' sense of position ' is so acute, that one who is not thoroughly familiar with it would be tempted to deny that the rats are anosmic. What especially gives them the appearance of smelling is the fact that the movements produced in ' sniffing ' and the movements of the vibrissæ are still present after the operation. That these are largely tactual reflexes is shown by the fact that they still persist even after a large part of both of the frontal lobes is removed. (Two animals were thus operated upon.)

One characteristic test will be given in detail: Undiluted oil of cassia was put down on the floor of the gallery just around the corner marked *r* in our diagram. This was allowed tò dry thoroughly so that the contact conditions would not be altered. The following description of the behavior of the

blind and the anosmic rats to this disturbing element in the maze is taken from our diary:

Blind Rat I.	1st trial.	Stopped .13 min. at the cassia. Total time: .36 min.
Blind Rat I.	2d trial.	Stopped .25 min. *Decided not to pass it and returned home,* running into the first cul-de-sac (something he has not done for weeks). Taking up his cue again, he started to the food-box but stopped again at the cassia for .08 min., then passed it and went to food. Total time: .83 min.
Blind Rat II.	1st trial.	Paused at cassia but did not linger. Time: .20 min.
Blind Rat II.	.2d trial.	Paused at cassia but did not linger. Time: .20 min.
Blind Rat III.	1st trial.	Came to dead stop at cassia and waited there .08 min. Total time: .26 min.
Blind Rat III.	2d trial.	Stopped for .08 min. at cassia. Turned and went home. On return went into the cul-de-sac, emerging he turned corner at *r* but again could not stomach cassia. Turned into cul-de-sac *B* and apparently was utterly confused. After this he made several trips between *O* and cassia. Again and again he stuck his nose into the turn smelling of the cassia, but he would not pass it. At the end of 9 min. he was taken out and petted and later was tried in the maze. He could not be prevailed upon to pass the cassia. It was several days—although we had assiduously scoured the maze after the rat's first day's trial —before he finally crossed the place smelling of the cassia.
Blind Rat IV.	1st trial.	Paused at cassia and sniffed but did not delay his journey to the food-box. Time: .23 min.
Blind Rat IV.	2d trial.	Repeated the behavior of first trial. Time: .25 min.
Anosmic Rat *Y.*	1st trial.	Passed like a streak over cassia. Time: .20 min.
Anosmic Rat *Y.*	2d trial.	Passed like a streak over cassia. Time: .16 min.
Anosmic Rat *Z.*	1st trial.	No sign of noticing cassia. Time: .21 min.
Anosmic Rat *Z.*	2d trial.	No sign of noticing cassia. Time: .18 min.
Anosmic Rat *A.*	1st trial.	Did not notice cassia. Time: .23 min.
Anosmic Rat *A.*	2d trial.	Did not notice cassia. Time: .18 min.
Anosmic Rat *B.*	1st trial.	Did not notice cassia. Time: .20 min.
Anosmic Rat *B.*	2d trial.	Did not notice cassia. Time: .20 min.
Anosmic Rat *D.*	1st trial.	Was not hungry so could not get him to go to food, but in his 'loafing' *he passed and repassed cassia many times.* At no time did he show any signs of noticing it.

We think that the above tests are striking enough to convince any one that these five rats did not smell. We, ourselves, after viewing the operation to remove the *bulbi olfactorii* were

convinced that if the rat ever smelled again, either of two facts would have to be assumed: First, that central regeneration had taken place; or, second, that the N. Trigeminus functions as an olfactory structure. In regard to the first point, we shall say that histological examinations now going on will show whether or not any central regeneration has taken place, or is in the process of taking place in these rats. There is no evidence gathered from our experiments which tends to show that these rats can smell, consequently we have no ground for assuming *a priori* either that regeneration has taken place or that the N. Trigeminus functions as a specific olfactory structure.[1]

Before concluding this discussion of the learning process of the anosmic rats, it remains to be noted that we did not (as was the case with the blind rats) remove the *bulbi olfactorii* from rats already trained to the maze. We justified ourselves for taking this position by assuming that if the anosmic rats could *learn* the maze *as rapidly* as the normal rats, no experimental evidence would be needed to support the inference that the rats could still run the maze if they were forced to lose their sense of smell.

(d) *The Behavior of Anosmic Rats Trained to the Maze in the Light, when Introduced to the Maze in Darkness.*

The five anosmic rats, after having had their fifty trials in the light, were tried five times each in the maze with the light excluded (see conditions of this test, page 36). We present below the five records of each rat made in the dark with a comparison set of records of each rat made 4 hours previously in the light.

With the one exception the records in the dark are practically equal in point of time to their companions in the light. There is a slight tendency for the records in the dark to average a little higher than those in the light but whether this is due to accident or whether it marks a real difference in behavior cannot be decided from the limited number of records. The possibility is at hand, that the shutting off of the function of two sense organs tends to decrease the activity of the animal.

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[1] To settle this point absolutely, however, would take extended observations.

|	In Light.		In Darkness.	
	Trial.	Min.	Trial.	Min.
Rat *Y.*	1	.18	1	.26
	2	.18	2	.16
	3	.16	3	.16
	4	.16	4	.16
	5	.16	5	.25
Rat *Z.*	1	.30	1	.25
	2	.20	2	.23
	3	.20	3	.28
	4	.18	4	.21
	5	.16	5	.18
Rat *A.*	1	.25	1	.30
	2	.23	2	.33
	3	.21	3	.25
	4	.26	4	.33
	5	.26	5	.26
Rat *B.*	1	.23	1	.25
	2	.23	2 } Slight confusion in running the	.41
	3	.25	3 } first half of the maze.	.20
	4	.26	4	.20
	5	.25	5	.21
Rat *D.*	1	.25	Repeated the behavior of normal Rat II. Numerous tests were taken. He simply could not run the maze in the dark. Every time the room light was turned on he ran to the food-box. He likewise could run the maze when the miniature lights were caused to glow faintly. Detailed experiments were made, but the results are not presented because they are identical with those obtained from experiments upon normal Rat II. (see page 42). (This rat had developed a bad cough similar to Rat II.)	
	2	.23		
	3	.20		
	4	.23		
	5	.25		

(e) The Behavior of (Partially) Deaf Rats in Learning the Maze.

The two young females whose middle ear apparatus had been thrown out of function and whose period of convalescence has already been described, were next tried in the maze. Only eight days were allowed to elapse between the operation and the beginning of the trials in the maze. We feared that these animals might in some way remove the paraffine from the middle ear cavity and that a new tympanic membrane (at least one composed of scar tissue) might develop. Forcing the rats to learn the maze eight days after the operation in all probability removes such a contingency.

The rats suffered so few ill consequences from the operation, that we felt that their records could be relied upon. These two females, as has been stated above, were about 150 days old. They were exceedingly active. Below (Table XI, Curve XI.) we give the usual records of their trials in learning the maze.

TABLE XI. Showing the averages of two young (partially) deaf females in learning the maze.

No. of Trial.	Average. Minutes.	No. of Trial.	Average. Minutes.
1	16.53	12	.44
2	2.50	13	.23
3	1.48	14	.48
4	1.18	15	.28
5	1.20	16	.38
6	.84	17	.28
7	.70	18	.25
8	.38	19	.20
9	.61	20	.25
10	.78	21	.25
11	.34	22	.20
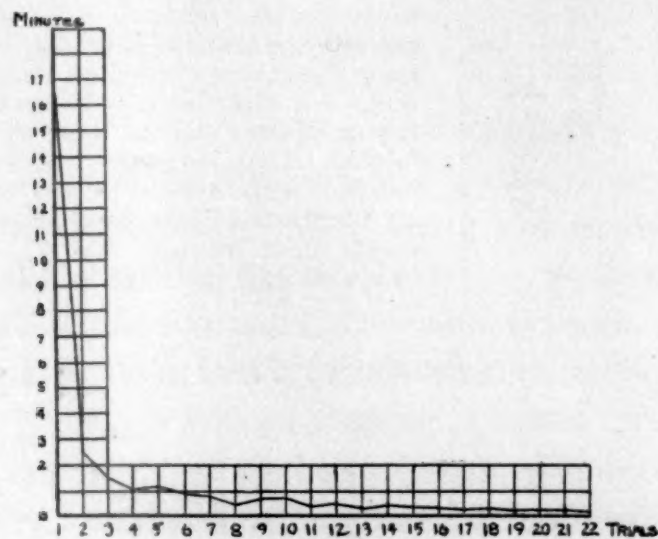
CURVE XI.   Constructed from Table XI.

As the records show, the behavior of these rats was perfectly normal. In fact, one of them undoubtedly ' holds the record ' in this laboratory for excellence in learning the maze. No peculiarity was noticeable in their behavior when passing from a long gallery into a short one and *vice versa,* or when passing entrances, etc., as one might expect would be the case

if the sensitivity of the tympana to changes in the pressure of the air columns is at all responsible for the formation of this association. At the end of this experiment the aural sensitivity of these rats was still markedly below normal.

IV. *Experiments Designed to Test the Function of Cutaneous Sensations in the Formation of the Maze Association.*

1. *The Effect of the Removal of the Vibrissæ from Trained Normal and Defective Rats.*

The vibrissæ of the white rat are long and numerous and exceedingly mobile—very similar to those of the cat except that the latter's are stationary. The rat's vibrissæ are in constant motion. Below, we present two drawings of these vibrissæ—one, the view from beneath the head, the other looking down from above. Especial attention is called to the fact that they project from the nose of the rat in five tiers. The vibrissæ nearest the anterior nares are most mobile.

On account of the extreme mobility of these hairs, we decided *a priori* that they must be of extreme usefulness to the rat in making his proximate orientation in the maze. We did not see how it was possible for them to serve as the basis for making the turns—*i. e.*, in any discriminatory way—but we felt that the vibrissæ would be indispensable to him in detecting an entrance or a wall (*i. e.*, at least to the blind animal). It is easily demonstrated by any one that the rat in learning the maze does not run into the cross pieces in the maze 'head on'—the vibrissæ undoubtedly warn him of the presence of solid objects. But when a labyrinth path is learned and the rat begins to traverse it with assurance, he will sometimes run head on into an obstruction placed in his way. This behavior suggests, to some extent at least that the function of the vibrissæ may be dispensed with once the pathway is thoroughly learned. A number of tests were made. As a preliminary to this test, we ran our normal, anosmic and blind rats around the maze for several days—until their time was minimum and constant from day to day. When they were in thorough training, with a reaction time for traversing the

maze from .20–.30 min., we proceeded as follows: First, in order to make sure that the rats were hungry, and that their reactions for that day could be trusted, two normal tests were
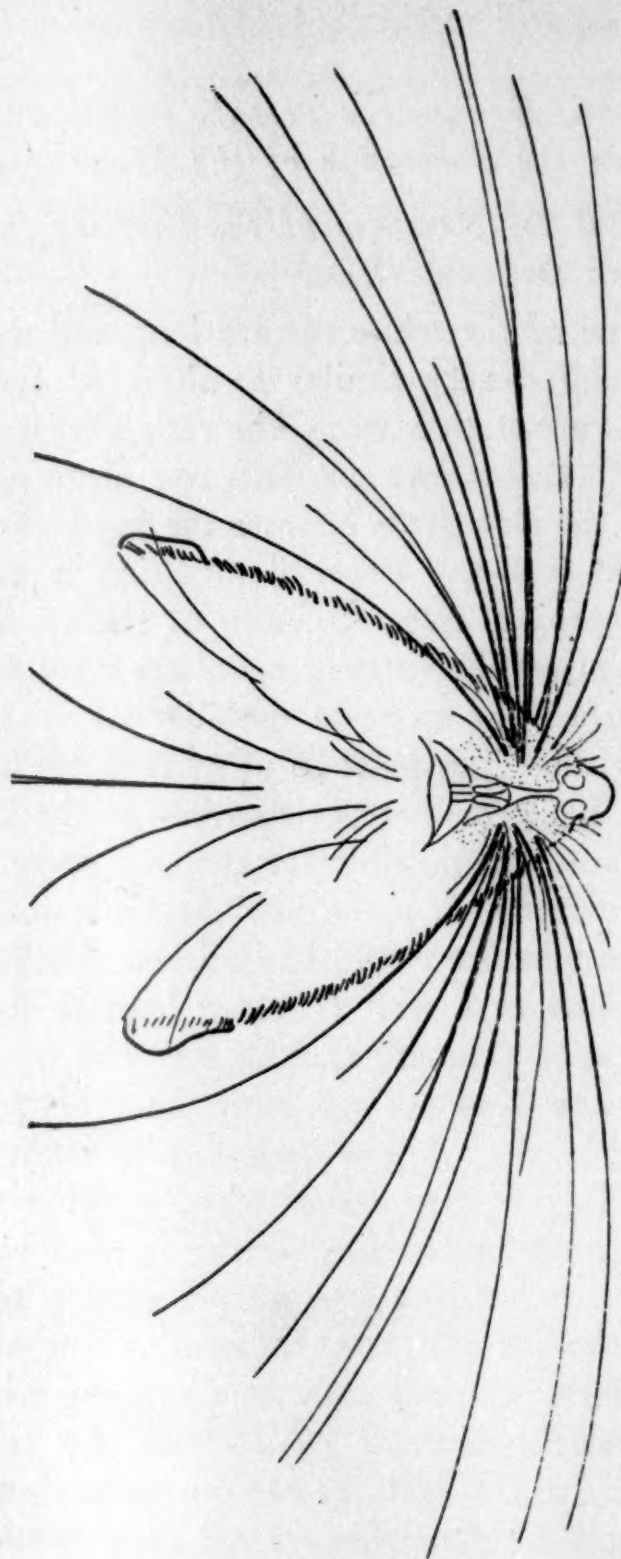
FIG. 3. Showing Vibrissæ of the White Rat—viewed from below. (Life size.)

given each rat before the vibrissæ were cut off. After the two normal tests had been given, the vibrissæ were closely cut
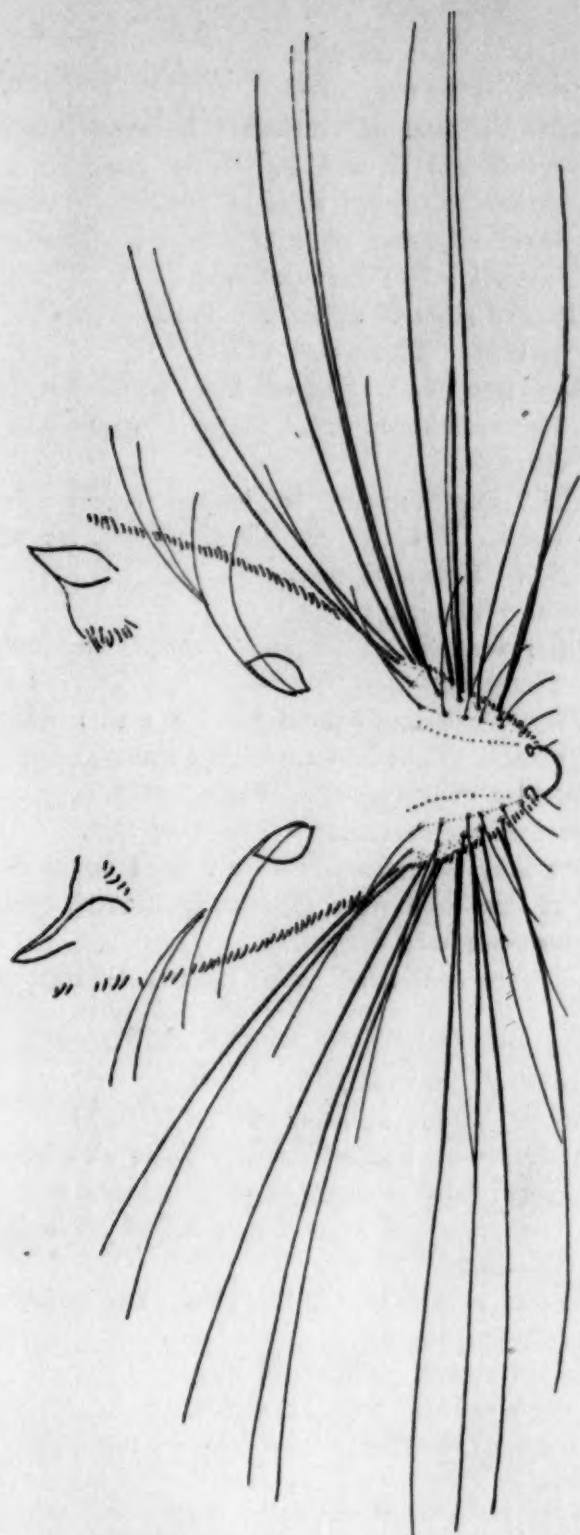
FIG. 4. Showing Vibrissæ of the White Rat—viewed from above. (Life size.)

off. The rats were then immediately tried in the maze. The results of this test are presented below.

Record of Two Blind Rats.

Rat I. 1st normal trial. Time: .25 min.

Rat I. 2d normal trial. Time: .25 min.

Rat I. 1st trial. After removal of vibrissæ. Bumped into sides. Ran into cul-de-sacs *A* and *B*. Went head on into nearly every corner. Hugged sides of galleries. Walked very slowly. Gave apparent signs of affective disturbance after butting into walls. Time: 1.28 min.

2d trial. Hugged sides of galleries. Walked slowly. Made no errors of turn. Time: 1.08 min.

3d trial. Ran into *A*. Bumped into walls but less than before. Gathered speed after center of maze was passed. Time: .50 min.

4th trial. Much improvement. No longer creeps. Does not butt into walls. Error at one place. Time: .42 min.

Rat II. 1st normal trial. Time: .25 min.

Rat II. 2d normal trial. Time: .25 min.

Rat II. 1st trial. After removal of vibrissæ. Duplicated behavior of Rat I. Time: 1.40 min.

2d trial. Very great improvement. No errors and no hugging of sides. Slight hesitancies. Time: .41 min.

3d trial. Further improvement. Time: .36 min.

4th trial. Further improvement. Time: .35 min.

Twenty-four hours later, these two rats were tried again in the maze. The reactions of the rats at that time were practically normal. After the first two trials, no sign of disturbance was noticeable.

Two anosmic rats were next tried under exactly similar conditions.

Record of Two Anosmic Rats.

Rat I. 1st normal trial. Time: .26 min.

Rat I. 2d normal trial. Time: .25 min.

Rat I. 1st trial. After removal of vibrissæ. Walks slowly. Butts into cross pieces fully as much as the blind rats did. Errors in turns. Gathers speed after the center of maze is passed. Time: 1.28 min.

2d trial. "Lets herself go." No error, but butted full into wall. Time: .56 min.

3d trial. Improvement. Time: .55 min.

4th trial. Improvement. Time: .51 min.

Rat II. 1st normal trial. Time: .21 min.

Rat II. 2d normal trial. Time: .20 min.

Rat II. 1st trial. After removal of vibrissæ. Butted full into wall at first turn. Picked herself up and fairly flew for the rest of the way. Time: .30 min.

2d trial. A little slow but steered herself through entrances and down center of galleries with all ease. Time: .35 min.

3d trial. We allowed her to eat too much on 2d trial and the edge had been taken from her appetite. Time: .50 min.

Twenty-four hours later, these rats gave normal reaction times—Rat II. going below her normal time as given above (1st, .20 min.; 2d, .23 min.; 3d, 18 min.; are her records on the second day's trial).

RECORD OF TWO NORMAL RATS.

Rat I. 1st normal trial. Time: .21 min.
Rat I. 2d normal trial. Time: .23 min.
Rat I. 1st trial. After removal of vibrissæ. Butted square into walls. Ran into cul-de-sacs. Hugged sides of galleries. Ran with jerks and starts. Clung to floor with feet (a very ludicrous bit of behavior). Time: .38 min.
    2d trial. Similar behavior. Time: .38 min.
    3d trial. No error. Hugged sides of galleries. Time: .23 min.
    4th trial. "Let himself go." Time: .23 min.
Rat II. 1st normal trial. Time: .17 min.
Rat II. 2d normal trial. Time: .16 min.
Rat II. 1st trial. After removal of vibrissæ. Clung to floor. Error in turn and ran full length of one cul-de-sac. Peculiar jumping movements. Time: .45 min.
    2d trial. After removal of vibrissæ. Reaction rapid but jerky. Time: .25 min.
    3d trial. Perfect. Time: .21 min.
    4th trial. Perfect. Time: .21 min.

The effect of the removal of the vibrissæ, even under the above conditions, viz., the removal of the vibrissæ and the immediate trial in the maze, was so transient, that we thought that by varying the conditions of the experiment somewhat we might eliminate any disturbance of the reactions. It is obviously unfair to the animal to try him immediately after removing the vibrissæ. The effect upon the emotional condition of the animal must at first be very marked. We ourselves feel ' queer ' when our finger nails are cut to the quick or when our hair has been closely cut—the effect is noticed more on the affective side than on the cognitive. After a day or two, however, our organism adapts itself to the changed condition and we cease to notice the ' feel ' of the closely cut hair or nails.

Thinking that a similar process of adaptation might go on in the case of the rat, we adopted the following procedure upon four trained rats—two normal rats and two partially deaf rats (whose records in learning the maze have been given) : On a given day, five normal reactions were taken. The vibrissæ were then removed and the rat put back into his cage. 48 hours later (rats having been fed once in the food-

box of the maze) the rats were allowed to run the maze. Below, we give respectively the five normal records and the records 48 hours after the removal of the vibrissæ.

TESTS ON NORMAL RATS.
Normal Trials.

Rat I.	1st trial.		Time: .23 min.
Rat I.	2d trial.		Time: .20 min.
Rat I.	3d trial.		Time: .21 min.
Rat I.	4th trial.		Time: .21 min.
Rat I.	5th trial.		Time: .23 min.

Tests After Removal of Vibrissæ.

Rat I.	1st trial.	Perfect.	Time: .23 min.
Rat I.	2d trial.	Perfect.	Time: .25 min.
Rat I.	3d trial.	Perfect.	Time: .26 min.

In all three trials this rat struck out into the open. There was no confusion, no hesitancy and no butting into walls.

Normal Trials.

Rat II.	1st trial.		Time: .25 min.
Rat II.	2d trial.		Time: .18 min.
Rat II.	3d trial.		Time: .18 min.
Rat II.	4th trial.		Time: .18 min.
Rat II.	5th trial.		Time: .20 min.

Records After Removal of Vibrissæ.

Rat II.	1st trial.	Perfect.	Time: .25 min.
Rat II.	2d trial.	Perfect.	Time: .21 min.
Rat II.	3d trial.	Perfect.	Time: .23 min.

TEST ON TWO DEAF RATS.
Normal Records.

Rat I.	1st trial.		Time: .26 min.
Rat I.	2d trial.		Time: .31 min.
Rat I.	3d trial.		Time: .25 min.
Rat I.	4th trial.		Time: .41 min.
Rat I.	5th trial.		Time: .36 min.

(Her normal reactions were usually slightly higher than the average.)

Records After Removal of Vibrissæ.

Rat I.	1st trial.		Time: .33 min.
Rat I.	2d trial.		Time: .33 min.
Rat I.	3d trial.		Time: .31 min.
Rat I.	4th trial.		Time: .33 min.

Her behavior was perfectly normal in every respect. There was no clinging to the sides of the galleries nor creeping around corners.

Normal Records.

Rat II.	1st trial.	Time: .20 min.
Rat II.	2d trial.	Time: .20 min.
Rat II.	3d trial.	Time: .20 min.
Rat II.	4th trial.	Time: .20 min.
Rat II.	5th trial.	Time: .23 min.

(This rat won the prize for excellence in *learning* the maze.)

Records After Removal of Vibrissæ.

Rat II.	1st trial.	Time: .18 min.
Rat II.	2d trial.	Time: .20 min.
Rat II.	3d trial.	Time: .16 min.
Rat II.	4th trial.	Time: .20 min.

From these experiments upon the removal of the vibrissæ, we think it safe to say, first, that under normal conditions the rat probably uses his vibrissæ to assist him in making proximate orientation in the maze;[1] second, in all probability the rat does not discriminate his turns by means of any data contributed by the vibrissæ; third, the immediate effect of the loss of the vibrissæ upon the ' steadiness ' of the rat's reactions in the maze is only transitory—the steadiness of the reaction being not at all affected if the rat is allowed to habituate himself to the environment of his living cage after the removal of the vibrissæ.

2. *The Process of Learning the Maze Without Vibrissæ.*

Professor J. M. Baldwin, who was present at several of the above trials, suggested that we allow two rats with vibrissæ removed to learn the maze. In the following table (Table XII.) and its graphical representation (Curve XII.), the average records of two female rats (age, four months) are shown.

As may be surmised from the foregoing curve and table, their behavior was quite normal.

[1] Be it understood, however, that we have no crucial positive evidence in support of this assumption. The evidence as it stands here proves unquestionably that the animal is not disturbed in his reactions by the removel of the vibrissæ if time is given him to wear off the unaccustomed ' feel of their absence '—but it does not give unequivocal positive evidence that they are even normally used by the rat in sensing openings, walls, etc.

TABLE XII. Showing the average time of two female rats whose vibrissæ had been removed in learning the maze.

No. of Trial.	Average. Minutes.	No. of Trial.	Average. Minutes.
1	6.89	15	.30
2	10.35	16	.35
3	5.75	17	.29
4	1.70	18	.54
5	4.68	19	.23
6	2.45	20	.35
7	1.25	21	.20
8	.45	22	.20
9	.50	23	.19
10	1.44	24	.24
11	.30	25	.20
12	.35	26	.20
13	.30	27	.19
14	.29	28	.20

CURVE XII. Constructed from Table XII.

3. *The effect of Altering the Temperature Conditions in the Maze.*

The question at issue under this heading is not, can the rat learn to associate a change of temperature with a certain movement of the body, but it is rather a question of existing fact—does he, as he traverses the maze, under unmodified conditions, utilize the possible differences in the temperature values to be found at the correct turns *versus* the incorrect? Such differences must be very slight if they exist at all. Thinking, however, that in addition to the slight absolute differences in the temperature of the various parts of the maze, that the correct turns as over against the incorrect might offer a difference in the reflection of the heat of the animal's own body (in the sense of ' facial vision ') we decided to make a test case. At the point marked 2 in the maze, we inserted a four inch

square copper plate (we had arranged for several such copper plates at the points marked 2, *a*, 6, *b* in the maze). The trained rats were allowed to run by this plate on their regular daily trips until they were accustomed to it. As a test, we cooled the copper plate to the *freezing point* and allowed two anosmic rats, two normal rats and three blind rats to run the maze. Every rat ' kited ' by the copper plate with no sign of disturbance in his time records. The cold plate was then replaced by a hot one (approximately 75° C.). All of the rats were again tried. No sign of disturbance was noted. (Three observers were present at this test and all agreed that in no case was there any sign of disturbance.)

4. *The Effect of Changing the Direction of the Air Currents in the Maze.*

For this purpose a large electric fan was used. A tiny flag, placed on the cover of the maze immediately above the entrance at *r*, showed at any time the direction of the air currents. The fan was first placed to the south of the maze. A heavy current of air was thus driven through the maze in a northerly direction (this is strictly true only of the galleries which run north and south). Before being tried in the maze, each rat was accustomed to the noise of the fan and to the heavy current of air by allowing him to run freely around the outside cover of the maze while the fan was in action. Each rat (three blind, two anosmic, two deaf and one normal) was given two trials with the air currents flowing from W.-E. Three observers watched the behavior of the rats—all agreed that it was perfectly normal in every respect. *No errors were made and in no case was the usual time of the trip lengthened.*

5. *The Effect of Local Anæsthesia.*

Ethyl-chloride was the anæsthetic used in the following experiments. It was used in preference to cocaine for the reason that cocaine, when applied in amounts sufficient to cause tactual anæsthesia, affects the musculature as well.

The first attempt to isolate the cutaneous impression from the kinæsthetic by the above method was made by anæsthetiz-

ing the soles of the feet of two blind rats. The ethyl-chloride was applied to the soles of the feet of these two rats three times at intervals of three to four minutes. After the last application, they were immediately put down in the entrance to the maze. The following records show that the reactions of the rat were not disturbed.

RAT I.

1st trial. "Feet made anæsthetic. This had absolutely no effect." Time: .18 min.

2d trial. "Reanæsthetized the soles of the feet with the same result." Time: .23 min.

RAT II.

1st trial. "Absolutely perfect." Time: .20 min.

2d trial. "Stopped in maze to bite his feet. No error." Time: .30 min.

One other test was made by anæsthetizing the nose of a trained anosmic rat. Her several successive reactions were not in the least disturbed, although the ethyl-chloride was very thoroughly applied.

Still another similar test, the result of which was likewise *nil,* was made. We applied a heavy coating of collodion to the anterior (bare) portion of the snout of a trained blind rat. Twenty-four hours later this rat was tried in the maze. His reactions were normal.

Summarizing the results of these necessarily inexact attempts to separate the cutaneous impressions from the kinæsthetic, we may say, briefly, that the indications point to the fact that the rat in no way uses his cutaneous sensations as a basis for ' sensing ' the correct turns in the maze as distinguished from the incorrect.

V. *Experiments to Determine the Delicacy of the Sense of Taste in the White Rat (viz., the Affective and not the Cognitive Reaction).*

In carrying out these experiments upon the maze, we were repeatedly asked the question, " How delicate is the sense of taste in rats? " Some hardily inclined visitors even went so far as to suggest that the sense of taste might aid the rat in making the correct turns in the maze! While having little

faith in the notion that the rat ' tastes ' his way around, still, in view of the fact that some general knowledge concerning the delicacy of taste in rats might possibly be of value in later investigations, we began experimentation in this field.

We finally adopted the following method, after many attempts to find a better one: Aqueous solutions, differing widely in percentages, were made of the four usual taste substances, salt, sugar (cane), hydrochloric quinine and tartaric acid. Small cubes of baker's bread saturated in these solutions were presented to the rats.   At first the bread was given in the food-box of the maze, but it was quickly found that the rats would accept the bread saturated with stronger solutions if it were presented to them in their living cages.   A small clean dish was placed in the cage to receive the bread.   This was washed after every test.   Likewise the experimenter's hands were washed after each experiment.   The rats were kept uniformly hungry.   Only three or four tests were given each day.   After the day's experiments were over the rats were fed with their usual amount of food.   Starting the tests for the day with one set of the different percentages of one of the taste solutions, we presented first the weakest solution, then the next stronger, etc., until the solution became so strong that the rat rejected it.   The percentage of the solution definitely rejected was noted and the next day the rat was given this percentage at the beginning of the experiment.   Since it would be impossible for this paper to present the results of all the tests made with the four taste solutions, we will give from our notes a complete account of only one set, and summarize the remainder.

<div align="center">

6/1/06.

QUININE SOLUTIONS.

Rat A (Anosmic).

</div>

.01 per cent. quinine. Accepted.
.05 per cent. quinine. Accepted.
.1 per cent. quinine. Ate small portion and then definitely rejected it.

<div align="center">

Rat B (Anosmic).

</div>

.01 per cent. quinine. Did not seem to relish it.   Ate it nevertheless.
.05 per cent. quinine. Ate it very slowly.
.1 per cent. quinine. Rejected it.

Rat D (Anosmic).

.01 per cent. quinine. Ate it very slowly.
.05 per cent. quinine. Rejected it after taking a small amount.
.1 per cent. quinine. Rejected it.

Rat Y (Anosmic).

.01 per cent. quinine. Accepted.
.05 per cent. quinine. Ate it very slowly.
.1 per cent. quinine. Rejected.

Rat Z (Anosmic).

.01 per cent. quinine. Accepted.
.05 per cent. quinine. Accepted, ate part, left it, returned and finished eating it.
.1 per cent. quinine. Rejected.

Four Blind Rats.

All ate the .01 per cent. and the .05 per cent. solutions. Rats II. and III. actually ate a small portion of the .1 per cent. solution.

6/2/06.

Rat A (Anosmic).

.1 per cent. quinine. Tasted it and rejected it but came back and ate one-third.

Rat B (Anosmic).

.1 per cent. quinine. Tasted it and turned away. Came back, tasted and finally rejected it.

Rat D (Anosmic).

.1 per cent. quinine. Ate small portion and rejected rest.

Rat Y (Anosmic).

.1 per cent. quinine. Ate nearly one-half of it.

Rat Z (Anosmic).

.1 per cent. quinine. Rolled bread over with paw after tasting. Finally ate one-half.

Blind Rats.

All ate a part of the bread. They would take the morsel, drop it, pick it up again and again drop it. After a time, interest in the food was lost. Finally they came back to it and consumed a very small portion. At the end of one hour, the four small pieces were not completely consumed.

Normal rats were tried in the same way and with identical results. The question may be asked how we came to select the .01 per cent., .05 per cent. and .1 per cent. solution of quinine. Our answer is, that all solutions weaker than these were wholly unnoticed. We began the experiments by making solutions near the human cognitive threshold, but it was quickly found that humanly speaking the rats affective reaction to

bitter is a very gross affair. Certainly, we should have to be almost frantic with hunger before we should eat food soaked even in a .01 per cent. solution of quinine. Particular pains were taken to see that the rats were not frantic for food. Many tests were made with rats whose appetite had lost its edge through partial feeding—even under this condition, they would often accept the food soaked in .05 per cent. solutions and always that soaked in the .01 per cent.

Summarizing the remainder of the results upon these taste experiments, we find:

1. Solutions of cane sugar—at least up to 80 per cent.— are accepted eagerly.

2. Tartaric solutions are accepted in most cases up to 1 per cent. Rejection begins at .5 per cent. when passing from weak solutions to stronger; when tested at the beginning of the day's experimentation with a 1 per cent. solution, a small quantity of it is sometimes taken.

3. Salt solutions are accepted without question up to 5 per cent. Rejection is apparent in a large majority of the cases at this point. A few cases were noticed where a small amount of the 10 per cent. solution was taken.

If we may be allowed to draw any conclusions whatever from these crude and inexact tests upon the taste sensitivity of the rat, we should say that the indications are that the sense of taste in these animals is far too blunt to give any sensory data which could guide them in their journey through the maze.

VI. *Some Preliminary Experiments Bearing more or less Directly upon the Present Problem.*

1. *Experiments Designed to Test how Readily the Rat can Orient Himself when Put Down at Various Places in the Maze.*

In learning the maze, as has already been mentioned, the rats often return to the starting point for a new ' cue ' after having gone a certain distance toward the food-box. Gradually this tendency disappears and the rat becomes more and more competent to pick up the true pathway even after com-

ing out of a cul-de-sac. What happens when a perfectly trained animal is put down at such places as those marked X_1, X_2, X_3?[1] Has he the power to pick up the true pathway immediately at any point in the maze—no matter whether a forward or backward orientation has been given his body? Or must the animal go backward or forward around some corner or corners before he 'senses' his position in the maze? To take a specific example: Suppose a rat to be put down with wrong orientation at X_1. Will he turn immediately and scamper for the food or will he go on around s and t before turning and proceeding in the right direction?

To answer these and similar questions, some two hundred trials were made. Of these trials, 98 were made at the point marked X_1—the rest were made at X_2 and X_3. Our method was as follows: The rat was given a preliminary 'run' to freshen up his 'knowledge' of the maze. He was then put down at X_1 with his head pointed in the right direction (toward the food-box) and his efforts to orient himself were noted. At the next trial he was put down with his head pointed in the wrong direction (towards entrance) and similar records were made of the process of orientation. The tests are most satisfactory if the animal is allowed to have a small bit of food in his mouth when he is put down in the maze. He stops to eat this before beginning the act of orientation. This gives the experimenter time to close down the cover of the maze and to withdraw. The first question which comes to one's mind in such a test as the above is this, has the rat a natural tendency to turn around when put down in a gallery? We cannot answer this with certainty but our experiments enable us to state that in the 98 trials given in X_1, the animal went straight ahead in 47 cases and turned in 51 cases, regardless of the orientation given his body. On the whole we should say then that the tendency to turn and the tendency to go straight ahead are about equal.

Coming to the facts of orientation, we find: First, that in 59 cases out of the 98 (60.2 per cent.) given at X_1, the orientation was immediate. That is, if the animal was put down

[1] See cut of maze, p. 10.

with wrong orientation he turned immediately and went to the food box; if put down in the maze with right orientation, he went straight forward. But in these 59 cases, in addition to those already mentioned, we have included all those cases where an animal, put down with right orientation, turned 360° before starting to the food-box (about 12 per cent. of the total number of the cases of right orientation) and all those cases where an animal, put down with either right or wrong orientation, picked up his ' cue ' somewhere on the straightaway at X_1, i. e., picked up the pathway without having to turn a corner.

To explain this a little further, let us suppose a rat to be put down at X_1 with wrong orientation; sometimes he would proceed with that orientation for only 15–20 cm., then suddenly, before turning the corner at s, he would turn at 180° and scamper for the food-box. Now suppose that we put him down at X_1 with right orientation; he would sometimes turn 180° and go back for 15–20 cm., but before turning the corner at s, he likewise would turn again 180° and scamper for the food. Second, in 38 cases out of the 98 (39.8 per cent.), the orientation was made only after turning corners. If the animal was put down at X_1 with wrong orientation, he would proceed on around s and r, continuing often into one of the cul-de-sacs A or B; emerging from either of these, he would pick up the true pathway and dart off immediately. If put down with right orientation, he would turn and behave exactly as in the preceding case. In a few of the cases, the animal rightly oriented would proceed with that orientation around t and u, he would then turn and go back, possibly to t or s before again turning for the last time. In 7 of the cases, the rat went completely back to the entrance before getting his ' cue.' The singular part of it all is, that when the animal gets his cue in any part of the maze, he gets it just as definitely there as at the entrance. Very rarely was an error made after the animal became oriented, i. e., after he had started off ' hard.'

So far as our records go, they show that the blind and

anosmic rats oriented themselves fully as well as the normal animals.

The results of the tests made at X_2 and X_3 are very similar to those at X_1.

It would be interesting to know in those cases where orientation did not take place immediately whether it was necessary for the rat to turn the corners in order to get his bearings. This question cannot be adequately answered by experiments upon our maze—the straightaways are far too short.[1] If the animal moves either forwards or backwards for any considerable distance, he must inevitably turn a corner. While a large number of the tests show that the rats do make the turns before obtaining the correct orientation, we are not justified in assuming that the turning *per se* gives the cue to orientation. In the near future we hope to construct a maze having a six-foot straightaway somewhere near the center of the course. Under such conditions, it may turn out that the rat can orient himself without rounding corners. The fact that so many of the above orientations were made 'immediately' lends some support to the view that the act of turning *per se* is not a *conditio sine qua non* to the process of orientation. (There is, as everyone can see, a large source of possible error in our percentage of right orientation. We have not excluded the possibility of the animal's *learning to turn, i. e.,* irrespective of the 'sensing' of his position in the maze. There is no reason to suppose that such an association would not be established provided the animals were given a sufficient number of trials. In the above tests, the animals were given about 12 trials each.)

Until the facts of orientation in the maze are more clearly established, we feel sure that it would be futile to discuss the 'control factors' by means of which the rat 'finds' his position in the various parts of the maze. In view of the fact, however, that we shall take the position in this paper that the kinæsthetic impressions coupled with certain other intra-organic impressions are the only necessary sensory factors used in the

[1] Nevertheless a complete answer will have to be returned to this question before we can advance any but a very tentative theory of how the rat 'controls' his kinæsthetic sensation series.

formation of the maze association, it remains to be said (in our opinion at least), that the above results concerning the facts about orientation offer no insurmountable difficulties to such a view.

2. *The Effect of Rotating the Maze.*

After the failure of our attempts to disturb the reactions of the rat by modifying the conditions in the maze, we were ill prepared to find that the simple rotation of the maze 90°, 180°, etc., would have serious consequences upon his behavior. We probably should have been prepared for such consequences, however, because the so-called ' sense of position ' (' sense of direction '?) in this animal is extremely well marked.[1] Small has already mentioned this fact and we have had many occasions to observe it anew in our further work with these animals. The facts come out quite clearly in the behavior of a rat when at work upon a problem box such as that described in *Animal Education* (p. 13), where the first step in obtaining the food consists in scratching away the sawdust from one end of an oblong box. If, after the animal has once or twice successfully obtained food by entering at a given end of the box, the box now be rotated, *e. g.*, 45° or 90°, the animal becomes confused and is likely to scratch at the former position of the end of the box. It takes him some little time to adapt himself to this simple change in the orientation of the box. Again, a curious disturbance of the same kind was noticed in some of Mr. Peterson's rats. He was testing the rats with a small problem box having a door in one side which was held in place by a latch. A spring opened the door of the box when the

[1] If this sense of direction should be established by further tests, its experimental demonstration should date back to Bethe's work upon the rotation of the bee-hive. For a short review of his tests, see the review of the Peckham's book, *Wasps, Social and Solitary*, Psychological Bulletin, Vol. III., No. 5, p. 172. Many other references might be given to the legions of articles on the flight of pigeons, etc., but none of the experiments cited in them in support of a sense of direction is controlled in any proper sense. Porter's experiments on the reversed maze (Am. Jr. of Psy., Vol. 17, p. 256) are open to the objection that the environment was not ' reversed ' at the time of the reversion of his maze. Bethe's experiments are likewise open to the same objection. In the experiments which follow, the blind and anosmic animals furnish complete control in tests of this kind.

latch was thrown up from its socket.   The usual large experimental cage was placed over the small problem box.   The door of this latter box always, *e. g.*, faced the north.   The rat to be tested was admitted through the side of the experimental cage facing east; consequently, in order to reach the door of the problem box, he would have to go almost due west.   If, after the animal learns the problem in this way, the door of the problem box be made now to face west, and the animal be admitted on the north side of the experimental cage, his reaction times for the first two or three trials are considerably increased.[1]

It would seem then, if these observations are at all worthy of trust, that the rat is in some way sensitive to changes in absolute direction.   This position is possibly further supported by the results we obtained from experiments on the rotation of the maze.   Our blind (3), anosmic (2), partially deaf (2) and normal (2) rats were again the subjects under observation.   These rats were trained to the maze with the entrance south (see cut, p. 10).   They have been the subjects of so many experiments that they were thoroughly automatic in their reactions.   The rats, in the normal reactions from day to day, maintained a remarkably low mean variation in their time; consequently any disturbance in their reactions which may be noted below is unquestionably due to the effects of the modification of conditions.

The first test was made after the maze had been rotated 180°, *i. e.*, absolute direction of north and south interchanged. (*It must be observed that in all of these rotation experiments no single relation within the maze was altered thereby.   The animal still turns to the left or to the right as he has always done—nothing is changed except the absolute direction.*) The normal reaction time of these rats should be placed approximately at .26 min.

EFFECT OF ROTATING MAZE 180° UPON, (*a*) ANOSMIC RATS.

Rat I. 1st trial.   No errors but slow.   Time: .41 min.
Rat II. 1st trial.   No confusion.   Time: .28 min.

[1] These statements are made on the basis of chance observation.   We did not at the time appreciate the possible bearings of the phenomena observed and consequently made no effort to control them.

Second Day's Experience.

Rat I. 1st trial. Badly confused. Ran into *A*. Came back home. Took cue there but ran into *B*. Forward again but ran into *F*. Butts into cross pieces and sides of galleries with her nose. Time: 1.00 min.

2d trial. Ran full length of *F*. Time: .35 min.

3d trial. Hesitated at turns. Time: .28 min.

4th trial. Became confused after starting and returned home. Time: .45 min.

Rat II. 1st trial. Lacks confidence. Makes no errors but hesitates at every turn. Time: .41 min.

2d trial. Repeated above. Time: .31 min.

3d trial. Made error by running into *A*. Started into *B* but withdrew and went on. Time: .38 min.

4th trial. Perfect. Time: .28 min.

(*b*) Partially Deaf Rats.

First Day's Experiences.

Rat I. 1st trial. Badly confused. Made every error in the maze. Time: 1.45 min.

2d trial. Perfect. Time: .26 min.

3d trial. Perfect. Time: .28 min.

Rat II. 1st trial. Ran into cul-de-sacs *A* and *B*. Two other marked hesitancies. Time: .66 min.

2d trial. Made two errors in cul-de-sacs. Time: .46 min.

3d trial. Error in *C*. Time: .55 min.

4th trial. Error in *E*. Time: .45. min.

Their second day's experience with the maze in this position showed practically normal reactions.

(*c*) Normal Rats.

First Day's Experiences.

Rat I. 1st trial. Absolutely lost. Ran into all the cul-de-sacs. Back home, etc. It was like learning the maze for the first time. Time: 2.31 min.

Rat II. 1st trial. Badly confused. Errors in cul-de-sacs and hesitancies. Time: .68 min.

Second Day's Experiences.

Rat I. 1st trial. Ran into *B*. Hesitant. Time: .48 min.

2d trial. Error in *C*. Time: .55 min.

3d trial. Error in *C*. Time: .35 min.

4th trial. Perfect. Time: .25 min.

Rat II. 1st trial. Butted head squarely at first turn but was very rapid in movement. Made no errors. Time: .25 min.

2d trial. Slight hesitancy at one turn. Time: .25 min.

3d trial. Perfect. Time: .21 min.

4th trial. Perfect. Time: .21 min.

(*d*) Blind Rats.

Here we received our second shock. *The blind rats were not in the least disturbed by this change in the position of the maze.* In view of the unchanged

behavior of the blind rats, the first thought which occurred to us, naturally, was, that vision must after all play some rôle in the maze association. But since we had accumulated so much evidence against this view, we decided to reserve judgment until the blind rats, as well as the others, had been given other trials with the maze in different positions. All the rats were run through the maze with the entrance north (its position in the tests described immediately above) until they were thoroughly familiar with it in that position. This took about 12 trials (3 days). The maze was then rotated 90° throwing the entrance to the east.[1] *All the rats were badly confused. The confusion in nearly all cases being more marked than in the preceding test.* We cite in detail the behavior of the blind rats.

Rat I.　1st trial.　Started to right instead of to left. Prolonged hesitancies but no pronounced errors of turn. Time: .46 min.

　　　　2d trial.　Perfect. Time: .21 min.

　　　　3d trial.　Perfect. Time: .20 min.

　　　　4th trial.　Perfect. Time: .26 min.

Rat II.　1st trial.　Uncertain in all his movements. Went full length of *B*. Bumped into wall. Went back into *A*. Hugged wall all the way. Absolutely lost. Went back to entrance. On return butted squarely into wall at first turn. Ran full length of *F*. Time: 2.41 min.

　　　　2d trial.　Butted wall. Hesitancies. Full errors in cul-de-sacs. Time: .51 min.

　　　　3d trial.　Bumped into wall. Started into *B*. Time: .38 min.

　　　　4th trial.　Bumped into wall. Started into *B*. Time: .40 min.

Rat III.　1st trial.　Butted squarely into walls several times. Much hesitation. Time: .35 min.

　　　　2d trial.　Perfect. Time: .21 min.

　　　　3d trial.　Perfect. Time: .23 min.

　　　　4th trial.　Perfect. Time: .23 min.

After all the rats had become accustomed to the maze in this position (entrance east), the maze was turned back to its original position (entrance south): *All the rats were again confused—the blind rats being as much affected as the others.* After the rats had again become familiar with the old position of the maze, it was again rotated 90°, this time, however, the entrance was placed to the west. Marked confusion, similar to that described above, was observed in the behavior of the rats; the blind rats, however, being the least affected by the change.

As a further check upon our work, we ran our rats again with the maze in the original position (entrance south), until their reactions were normal; we then carried the maze as it stood,

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[1] *I. e.*, 270° from the original position.

straight south for a distance of about eight feet. This markedly changed the visual relation existing between the maze and that part of the room in which it usually stood. In thus moving the maze, it happened that it rested in its new position midway between two large windows: *None of the rats was affected by this change.* We then altered the direction of the light (strong sunlight) by pulling down first the shade to the left of the maze, and then the one to the right and finally both. Altering the direction of the light and decreasing the intensity of the light—even while the rat was *en route*—had not the slightest effect upon his behavior.

While we dislike to leave this problem in its present state,[1] it is necessary to do so, in view of the fact that its discovery came so late that we had no time to construct apparatus suitable for carrying out further tests upon it, before the publication of this paper was made necessary. We are at present engaged in constructing a self-rotating maze, the position of which can be changed to any desired angle. The tests must be made undoubtedly upon a large number of animals, normal, anosmic and blind, and possibly upon animals whose semicircular canals have been destroyed. And since the blind rats did better in these tests on the whole than those with vision intact, we must construct our maze so that the visual environment of the maze will rotate *pari passu* with the maze itself.

Until our experimentation has gone further, we shall not hazard any ' explanation ' of these disturbances in the reactions of the rat. The possibility suggests itself, however, that the semicircular canals are in some way responsible for it, but *how* they are responsible for it—if they do figure in it at all—is at present beyond our knowledge.

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[1] Since the above statements were written Miss Vincent has kindly repeated these experiments for the author upon a different maze, the plan of which, however, was identical with the previous one. Four normal animals were used. Great care was taken to keep the maze level both in the position of the original learning and in the rotated position. Her results harmonize throughout with the above. Experiments were also made to determine how sensitive these animals are to changes in position in the horizontal plane. It was found that they are not very sensitive to such changes since one corner of the maze can be lifted as high as 2½ inches without disturbing the reactions of the animal.

PART C.

SUMMARY AND CONCLUSIONS.

Let us bring together, as briefly as possible, the main facts which the present paper attempts to contribute.

1. We have established the time of the normal process of learning the maze: In our 'normal control series' and in the 'combined,' we have a group of records which, we feel confident, shows all the essential features as regards, (1) the absolute time of the first, second and succeeding trials in the maze; (2) the average mean variation in time of the successive trials; (3) the maximal and minimal consumption of time at any trial; (4) the percentage rate of improvement from trial to trial. Outside of the usefulness of this combined record to serve as a basis of comparison with similar records of other animals, it has the more immediate function of serving as a standard with which the records of the defective rats may be compared.

2. Neglecting the behavior of the two rats whose records have been discussed in the text, we make the assumption with some confidence that vision plays no part in the maze association. In the case of the two rats which proved exceptional in this respect, we believe that we have proven, by the experiments with the miniature lights, that even they were not using vision in any critically discriminative way. In what way the light exerted its function upon their reactions does not appear so clearly—two possibilities are open to us: In view of the fact that they were not so healthy as the others, it is possible to assume that the light exerted a general tonic effect upon their organism; in the second place, we may suppose that the animal really 'sensed' a difference in brightness at the correct turns, and that this became associated with the kinæsthetic sensations of turning (the 'seat' of which possibly may be largely in the eye muscles). This hypothesis would make the

' memory ' of the turn still largely kinæsthetic with the added condition that the kinæsthetic series would not function properly at critical places without the assistance of the visual impulse to serve as an ' eye muscle pull.' We ourselves are inclined to accept the first hypothesis, although the fact that the rats really attempted to solve the problem in darkness militates against such a point of view. In all other cases, the rats gave as consistent reactions without vision as with it, viz.: (1) Rats trained to the maze in the light can run it perfectly in the dark; (2) normal rats can learn the maze as readily in the dark as in the light; (3) totally blind rats can learn the maze as readily as normal rats; (4) rats trained to the maze in the light suffer little loss in the accuracy of their adjustments to the maze if deprived of vision.

3. In view of the fact that five of our animals which were deprived of the sense of smell learned the maze in normal time, the evidence seems clear that olfactory sensations have no rôle in the selection of the proper turns in the maze. Added emphasis is given to this point of view, when we recall that two of our anosmic rats learned the maze in ' record breaking ' time.

4. Cutaneous sensations cannot, in our opinion, serve as the basis for making the correct turns in the maze, for the following reasons: (1) the vibrissæ, in all probability the most sensitive part of the cutaneous mechanism, can be dispensed with absolutely without disturbing the reactions of the animal, provided sufficient time is given him to ' wear off ' the unpleasant ' affective tone ' conditioned by their removal; (2) the experiments with the cooled and heated copper plates show that the slight differences in temperature existing in the maze have no influence upon the selection of a given turn; (3) the direction of the air currents in the maze likewise are without effect upon the selection of the turns; (4) after the application of a local anæsthetic to the soles of the feet and to the bare portions of the snout of the rat, his reactions remain unchanged.

5. While none of the animals experimented upon was

totally deaf, still the results obtained from those whose aural
sensitivity was markedly decreased show: (1) That audition
proper, in all probability, is not contributory to the formation
of the maze association; (2) that sensations set up in the
tympana by the changing pressure of the air columns (really
belonging to the cutaneous group) do not aid the rat in selecting
the turns. We are in no position at the present moment to
make any statements concerning the function of the static sen-
sations in this association. The rotation experiments suggest,
however, if our facts are genuine, either that static sensations
have a rôle or else that the rat has some non-human modality
of sensation which, whatever it may be, is thrown out of gear
temporarily by altering the customary relations to the cardinal
points of the compass ('sense orientation'). We have rea-
son to suspect that such a 'sense of orientation' functions in
many orders of animals. At present, we have the facilities
at hand to make tests upon the homing pigeon (similar to the
ones reported above). Something possibly may come in the
way of control over this 'sense,' even if further investigation
proves that the human organism is not supplied with it.

6. The sense of taste in rats, at least from the affective
standpoint, seems to be a crude affair. They will accept and
eat food soaked in high percentage solutions of salt and bitter
—food which we should reject even in times of a stockyard's
scandal, much more under conditions of hunger similar to those
obtaining in the rats at the time these tests were made. The
rats' sensitivity to sour substances is apparently more acute
than to any of the others, a 1 per cent. solution of tartaric acid
being almost uniformly rejected. Most human observers, we
believe, would agree that a 1 per cent. solution of tartaric
acid is far less disagreeable than either a 5 per cent. salt solu-
tion or a .1 per cent. quinine solution. It was found that all
percentages of cane sugar which would stay in an aqueous
solution at the room temperature were eagerly accepted by the
rats.

7. Are we not, then, forced to conclude that the white rat
makes the correct turns in the maze on the basis of the intra-

organic sensations—the kinæsthetic sensations coupled with
the organic probably, and possibly with the static? If we
grant that the negative evidence brought forward in this paper
is sufficient to establish the fact, that the process of correct
turning in the maze is not ' controlled ' in the rat by his extra-
organic sensations, then it becomes our duty to hazard some
hypothesis as to how the ' kinæsthetic series ' is controlled.
Turning for a moment to the human behavior and attempt-
ing to analyze the reactions of one in a situation similar to that
described above for the rat, we should find in all probability
that the ' kinæsthetic series ' of such an one could not be con-
trolled without tactual or visual data.

So far as we know, no human being has ever had to learn
so complicated a path under conditions where all the extra-
organic sensations were made impossible. It would be in-
structive to have this maze, as it stands, made large enough
for human beings. It could be built as a dark room and with
differences in contact values (floors, walls, etc.) approximately
equalized. The galleries should also be made large enough
to permit the experimentee to move without allowing his body
to touch the walls. Suppose now that we impose the follow-
ing conditions upon our experimentee: (1) That all bare parts
of the body be thickly covered and that the arms be bound to
the sides; (2) that both ears and nostrils be tightly plugged?
Under such conditions, *could he ever learn to run down the
center of the galleries for exactly the proper distances, making
the correct turns without in any way touching the sides of the
galleries or without feeling for the openings, and without
making an error or even slowing up his pace* (even provided
he were allowed to count his steps)? Granted that he had the
ability, could he ever become perfect in this operation, so far
as the elimination of errors is concerned, at from 7–10 trials,
as many of our rats do? We have serious doubts as to
whether the human being could learn the maze under such
conditions. Certainly we believe, that if he could so learn it,
it would be at the expense of infinite time and infinite patience.
And yet, as is well known, we do perform most of our habitual

actions largely by means of our kinæsthetic sensations. Even the traversing of familiar pathways becomes more and more automatic. If some one turns out the light on us before we are out of the room, we can continue our way without serious mishap. Some people can travel all over a large house filled with familiar objects without colliding with any of them. But such automatism while executed largely in kinæsthetic terms is every where ' *controlled* ' *by slight contact experiences* (when vision is excluded of course).

In our own case visual *imagery* would play a preponderating rôle. If we come in contact with a chair in a very dark room, the objects in which are familiar to us, the visual image of it is immediately aroused. Along with this image, there follows a series of images of the objects adjacent to the chair to which the natural spatial relations more or less clearly adhere. Visual-motor images of ourselves as turning (impulses) immediately arise which must, as is usually stated, reach the proper degree of intensity (James' anticipatory image) before the ensuing adjustment is made which is to lead to the reëstablishment of the automatic series. No one would dream of affirming that such a complexity in the cortical processes as this would call for could exist in the case of the rats.

Small in his discussion of what goes on in the ' mind of the rat ' says that he has found ' unmistakable signs of the presence there of motor images.' It is a little hard for us to see the necessity of motor images or even the functional value of images in a situation like that offered by the maze. Introspection in our own case shows that after we have thoroughly established a series of motor coördinations, we never thereafter are distinctly conscious of the separate elements of the automatic series; and even in the learning process we often establish such a series of coördinations in a more or less trial and error fashion.[1] Why, then, in the case of the rat, need we assume the presence of motor images? The only possible times we could assume that the cortical conditions in the brain of the

[1] That is to say we do at times establish a series of simple coördinations without having distinct imagery of any kind corresponding to the separate steps in the series, even in the learning process.

rat are at all sufficiently complex to warrant the arousal of an image, would be in cases of hesitancies or inhibitions shown at the turns, but even here we need not assume that images necessarily arise.

In such cases, however, as in certain others which we shall mention below, it is necessary to assume that the animal in some way ' senses ' that the group of sensations arising at the moment is not ' familiar.' The neural impulses underlying these ' unfamiliar sensations ' will sooner or later inevitably discharge into the motor region and there release a motor impulse; if the adjustment then following is ' sensed ' as ' familiar,' the animal goes ahead as before; if as ' unfamiliar,' he is at the mercy of his organism until a familiar one is hit upon.

The discussion so far has not touched upon the ' control factors ' in such a series of kinæsthetic sensations. To get even a working notion of how the various correct turns in the maze are made, it seems necessary to fall back upon the assumption which Small has already virtually made, viz., *that along with the kinæsthetic series as an integral and indissoluble part thereof, goes the ' sensing ' of the amount of effort put forth.* Making this assumption, let us see how it works out practically. In the maze, there are 27 turns from the entrance to the foodbox. Let us assume that each straightaway with one turn equals one complete unit of a system of 27 such units. Let us suppose, also, that the act of turning is the ' control ' element in each unit. What leads up to the act of turning? The ' feeling ' (probably only vaguely ' sensed ') which may be expressed anthropomorphically in these terms: " I have gone so far, I ought to be turning about now! " This would call for nothing but a crude sensuous level of intelligence plus the element of ' association '—and neural ' synergy ' at that, is all we ask for. This act of turning is the completion of the unit —the touchstone by which the success or failure of the act as a whole is tried. If the turn is made before or after the proper amount of energy is expended, the animal runs into the wall or else goes past the true entrance: *If, however, the turn is made at the proper stage* (and it has been shown that blind rats de-

prived of their vibrissæ can make these turns without allowing their bodies to touch the edges of the openings at the turns), *the animal may be supposed thereby to get a 'reassuring feeling' which is exactly comparable from the standpoint of control to the experience which we get when we touch a familiar object in the dark.*

If this is really a correct statement of the *modus operandi* of the process of traversing the maze, then it seems to us that the matter might be tested experimentally. Up to the present time, however, we have made no carefully controlled tests which might support this view. The reason for this lies again in the unsatisfactory maze with which we have been working. We have planned to construct a maze in which the straightaways can be shortened or lengthened without disturbing any of the *turning* relations. The advantage of this is obvious—if the above statement of the process is true, then for aught we can see to the contrary, at the present moment, a trained blind rat running the maze without vibrissæ ought to attempt to turn at the correct distance regardless of whether the entrance is there or not. (And so far as we have any evidence to the contrary, the normal rat running the maze without vibrissæ would behave in the same way.) Speculation, however, is fruitless and our hypothesis must await further work before it receives positive support.

In conclusion, we may say that the present paper does not attempt to advance our knowledge, on the positive side of the questions involved, one whit beyond the point where Small has already led us; we have attempted rather to convince ourselves by further experimentation that his conclusions to the effect that visual, olfactory and tactual sensations do not furnish the element of control in the maze association· are correct. In reworking this field, we have supported everywhere the negative contentions of Small. We no more than he, offer *positive evidence* that the kinæsthetic sensations are the all-important and only necessary factors in the maze association. Both of us alike used the method of elimination. But in leaving even the negative side of the question as Small left it—practically

without convincing support, it became necessary for some one to go over his ground, using more rigid methods of experimentation.   We feel that we are now in a position to *begin the study* of the positive aspects of the problems offered by the behavior of the rat in forming the maze association.

APPENDIX.

After our work had been completed up to the point indi-
cated above, it was suggested to us that we had not taken into
account a possible source of error in our final conclusions.   It
may be argued that we can easily conceive of an animal which,
in its normal condition, might use its eyes with a good deal of
effectiveness in making minute adjustments, yet when deprived
of vision might learn very quickly to depend upon the sense of
smell.   That vision may be substituted for smell in adjust-
ments made hitherto upon the basis of smell alone, when for
any reason the latter function is interfered with, is likewise an
equally possible contention.

Believing that the proof of the establishment of the maze
association in an animal deprived of the possibility of receiving
most of the important extra-organic sensory stimulations would
add the needed confirmation to our previous work, we removed
the eyes, the olfactory bulbs, and the vibrissæ simultaneously
from a young male rat on September 6, 1906.   There is no
need to describe the operations.   Naturally recovery was slow
in this animal.   A certain lack of tonicity was observable.
This was due in all probability to the loss of the customary
afferent stimulation coming from eye and nose.   The animal
finally completely recovered and is still alive (March 1, 1907)
and in absolutely perfect condition.   He shows the same eager
curiosity, which is so characteristic of the normal animal.

During the first thirty days of his recovery, the animal
showed no signs of hunger.   At the end of thirty days, he was
tried in the maze, but owing to the lack of the hunger stimulus,
he made no progress in learning it.   On account of his rather
feeble condition, we were afraid to keep him long from food.
On being admitted to the maze, he would advance for a few
steps and then settle down quietly in one corner.   If stimu-
lated, either by sounds, to which he was extremely sensitive, or
by slight contact stimulations, he would get up and continue

his journey, but even after reaching the food he would make no effort to eat it.

We then forced the rat to live in the food-box of the maze for several days (shut off, of course, from the rest of the maze). We supposed the animal would make some effort to return home if taken out of the nest at *H* and put down in the entrance at *O*. This was found not to be the case—the animal apparently being better satisfied to loiter in the galleries than to remain at home.

Finally, we adopted the rigorous procedure used with the normal animals. The rat was kept hungry and was fed completely only after finishing his daily quota of trips through the maze. This method worked like a charm. The animal grew physically stronger, his appetite became normal and he began to gain in weight. He began at once to learn the maze and finally became the usual automaton. The elimination of errors went on more slowly, however, than in the case of the normal animals and consequently the number of trials is greater in his case than in the former.

After the animal had thoroughly mastered the maze, his reaction times were not greater than those of the normal animals nor were they more variable than those of the normal rats. The following ten consecutive records illustrate this point admirably:

.19 min.	.22 min.
.23 min.	.23 min.
.21 min.	.23 min.
.16 min.	.20 min.
.21 min.	.23 min.

These records were taken immediately after the animal had just learned to eliminate all errors. From this point on he could be depended upon to do his work with steadiness unless some disturbing sound was made while he was passing some important turn in the maze. If even a slight noise were made at such a time, he would make a serious error, and unfortunately, this error was made on the succeeding trips at the same place again and again. If one such error were made, the connectedness of the whole series of movements was likely to be

interfered with—the animal would get hopelessly lost. When
in this condition, there was nothing left to do but to put him
back in his cage and let him ' sleep it off.'

One rather amusing error was made by this animal which
persisted for a long time after all others had been eliminated.
He would dash correctly from the entrance at O around as far
as r without making an error. He would invariably dash by
r the full length of his body (into B). He would swing
around immediately to his right, dash into r and make up for
the lost time during the rest of the journey. This mode of
procedure at r became fixed and we doubt if the error would
ever have been eliminated had not a happy accident intervened
at precisely the psychological moment. But on one of rat's
journeys the operator happened to cough once just as the animal
approached r. The disturbance caused him to turn to his right,
which led him directly into the right path. After this, the
animal eliminated this error (having occasional relapses). We
mention this incident because, in our opinion, it proves quite
conclusively that the rat had no supra-sensitive mechanism for
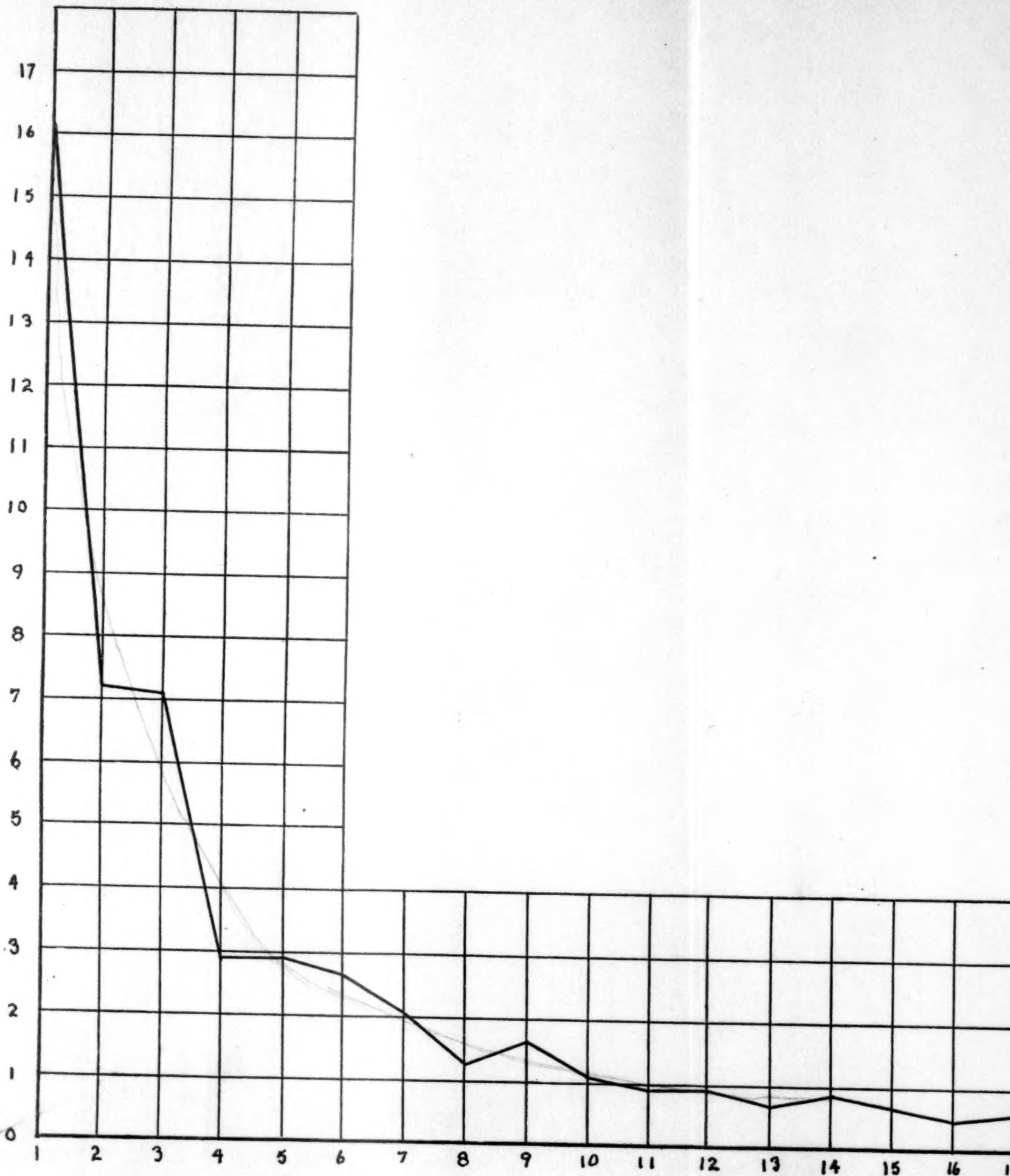detecting openings at a distance.

The reactions of this animal also were disturbed when the
position of the maze was altered with respect to the position
of original learning. The tests upon this point were made
exhaustive.

Finally, we may say, that in some ways the behavior of
this animal was more interesting, with respect to his sensitivity
to sounds, and to his adherence to certain errors, than that of
any of the other defective animals used in the experiments de-
scribed in this paper. If time had permitted, we should have
used more than the one animal, but we believe that even this one
animal establishes our main contention, viz., that the intra-
organic sensations are the only necessary sensory factors in
forming the maze association.

MINUTES

17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

1   2   3   4   5   6   7   8   9   10   11   12   13   14   15   16

CURVE III.   Showing the average time of ni

4

16   17   18   19   20   21   22   23   24   25   26   27   28   29   30   TRIALS

time of nineteen normal rats in learning the maze.